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A REPORT TO
DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
OF OPTICAL MEASUREMENTS OF SO_2 AND NO_2 AIR POLLUTION USING BARRINGER CORRELATION SPECTROMETERS

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Barringer Research Report No. TR69-113 entitled:

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ERRATA

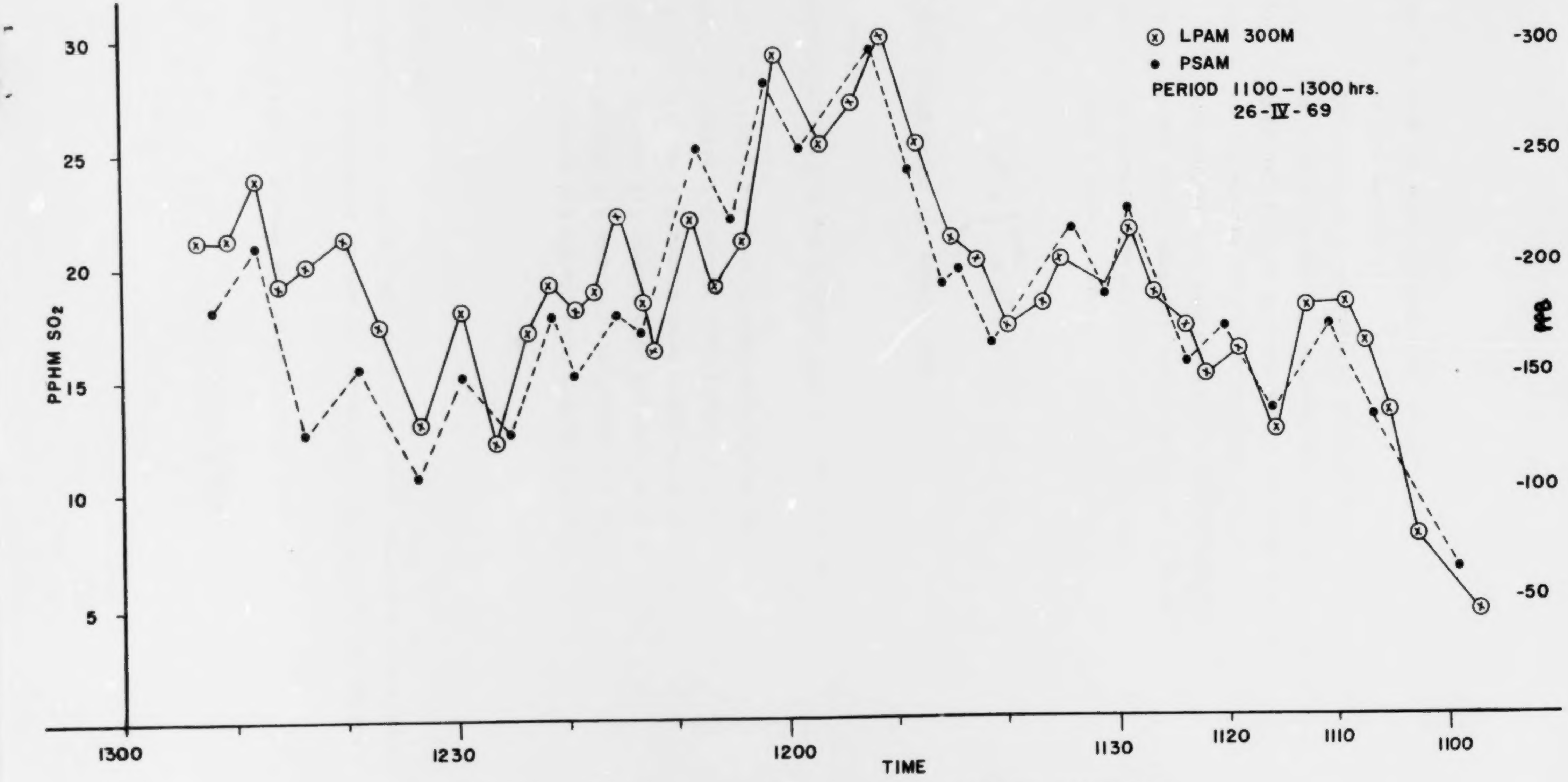
Page 88: - Figure 5.9 should read Figure 5.9 (a)
" 90: - Figure 5.6 should read Figure 5.9 (b)
" 90: - Figure 5.7 should read Figure 5.9 (c)
" 91: - Figure 5.8 should read Figure 5.9 (d)
" 98: - Figure 5.6 should read Figure 5.9 (b)
" 101: - Figure 5.9 should read Figure 5.9 (a)

The correct Figure 5.6 and Figures 5.9 (c) and 5.9 (d) are attached.

Page 70: - Equation (2) should read

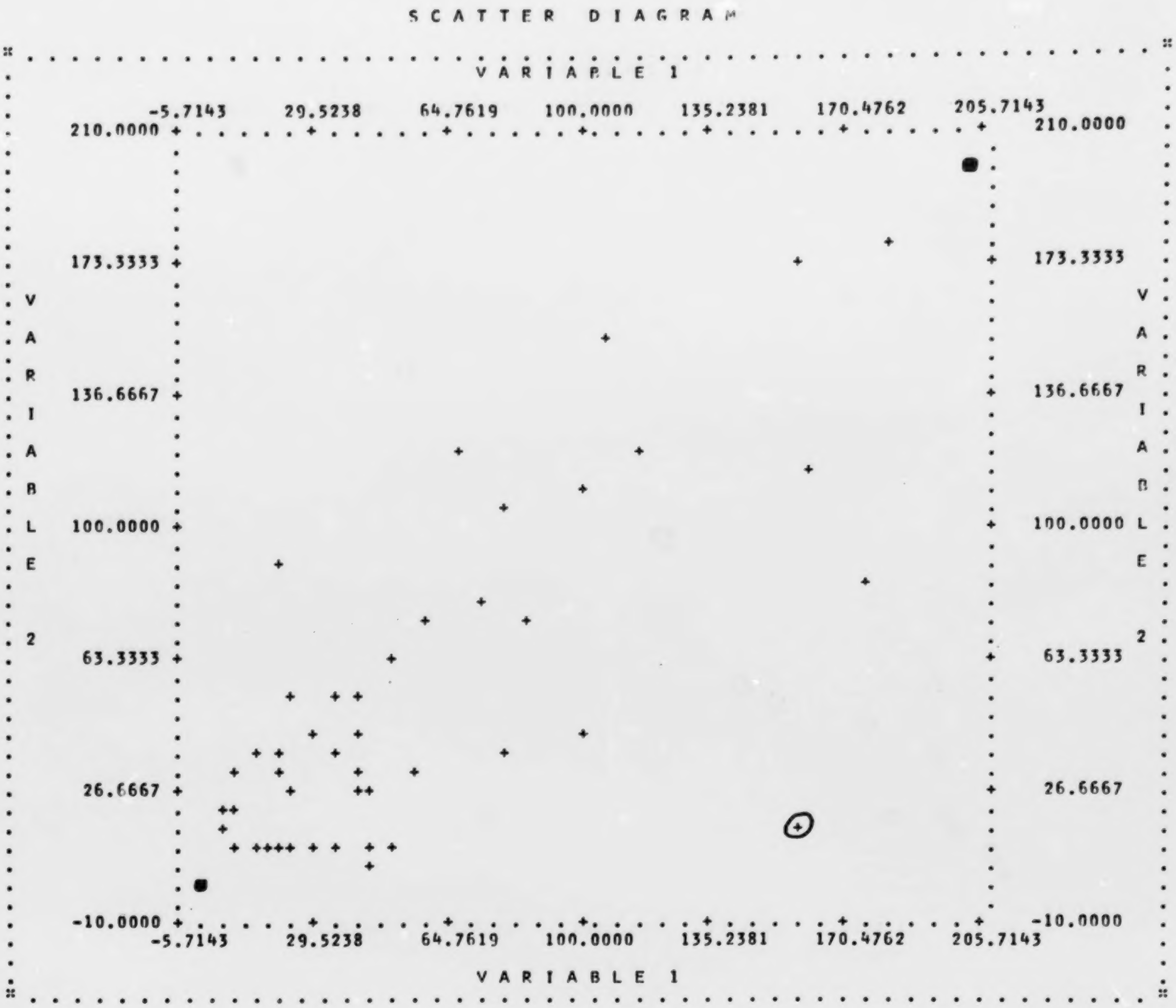
$$B_Z = \int_{Z=o}^{Z=\infty} \chi \, d_Z$$

" 85: - Line 8 should read "....3400°K"
" 88: - Correlation Coefficient should be 0.905
" 102: - Lower graph vertical scale should be "ppb SO_2"
The dotted line represents the LPAM readings.
" 108: - Line 9 should read "....10 pphm...."
" 130: - Vertical axis is NO_2 concentration with a scale of 1 cm = 10 ppm-m. (Curves are displaced relatively for clarity). Horizontal axis is distance in miles (scale unknown).
" 134: - Line 20 should start "NO_2 pphm...."



COMPARISON OF LONG PATH AND POINT SOURCE SAMPLERS

FIG. 5-6.



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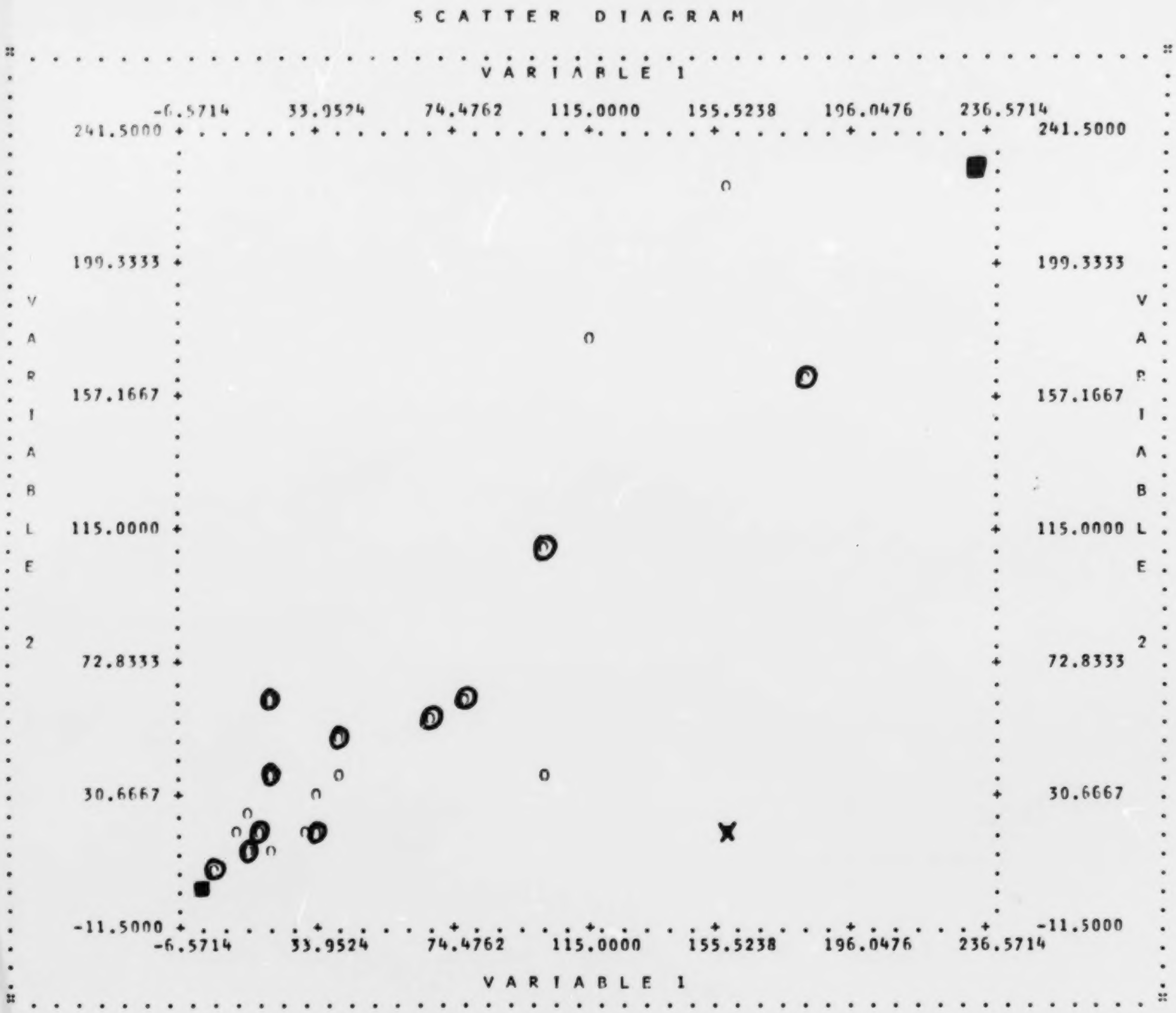
                                  INTERVAL SPACING      MINIMUM       MAXIMUM
SCALING FOR VARIABLE  1  ---         5.873016             0.          200.0000
SCALING FOR VARIABLE  2  ---         5.238095             0.          200.0000
```

FIGURE 5.9 (c)



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                                   INTERVAL SPACING        MINIMUM       MAXIMUM
SCALING FOR VARIABLE  1  ---          6.753968              0.          230.0000
SCALING FOR VARIABLE  2  ---          6.023809              0.          230.0000
```

FIGURE 5.9 (d)

A REPORT TO
DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
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OF SO_2 AND NO_2 AIR POLLUTION USING
BARRINGER CORRELATION SPECTROMETERS

PREPARED FOR
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EDUCATION AND WELFARE
Under Contract No. PH-22-68-44
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
Cincinnati, Ohio
PROJECT OFFICER: John S. Nader, Division of Chemistry and Physics

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Section 1

SUMMARY

This final report for the US Department of Health, Education and Welfare outlines work carried out under Contract No. PH-22-68 on the application and evaluation of a new measurement technique based on correlation spectrometry and developed by Barringer Research Limited. The Barringer technique of correlation spectrometry is a molecular absorption technique in which a portion of the desired spectrum containing rotation-vibration band structures is compared against a stored replica of the sought spectral signature contained within the spectrometer, thereby generating a real time readout of the quantity of target gas within the field of view of the instrument. The tests reported herein were designed to obtain preliminary data on certain air pollution problems which had been hitherto unobtainable by existing conventional measuring techniques.

The spectrometer can be operated in several modes, both active and passive, and hence provide for the first time means to examine basic air pollution problems for which data could not heretofore be obtained by existing conventional methods. The field work provided a more definative grasp on the basic air pollution problems of making representative SO_2 and NO_2 measurements. Tests were made to compare data derived from the operation of the spectrometers in their various modes with data derived from existing commercial instruments and wet chemical referee analyses.

Tests on boiler stacks have shown that the in-stack monitor can be used successfully for the continuous monitoring of the sulphur dioxide content of flue gases without any form of preconditioning. The remote sensor tests showed it was possible to measure the gas content of flue gas at the top of the stack during daylight when under conditions of good visibility. In the presence of aerosol and restricted visibility, the scattering effect of aerosol leads to low values. However, the correct values can be obtained by taking readings at various ranges and extrapolating the data back to zero range.

The airborne correlation spectrometer was used to study the oxidation of nitric oxide emissions to nitrogen dioxide downwind of the stack. Dispersion of the plume under the action of the gustiness of the wind leads to dilution of the flue gas and oxidation is substantially complete within a period of about 1 to 2 hours. The rate constant for the oxidation of nitric oxide to nitrogen dioxide by molecular oxygen is too small to account for the rapid buildup of NO_2 recorded by the airborne monitor. This suggests that some stronger oxidizing agent is present in the Ontario atmosphere to effect the rapid oxidation indicated by our data.

Comparisons of the use of the point sample ambient monitor and the long path ambient monitor indicate that while the two instruments remain substantially in phase to better than 90% (and especially when short optical path lengths were used on the long path ambient monitor), with pathlengths of the order of 1 mile, considerable concentration gradients can exist within the compass of the long path instrument. Then the average concentration can vary substantially from the point sample ambient monitor readings and occurs when isolated gas pockets or plumes are within its pathlength. The results indicate that the long path monitor will give much more meaningful averages and avoid extreme fluctuations associated with point samplers which are more strongly influenced by nearby sources and changeable micrometeorology.

Field tests of nitrogen dioxide concentration carried out in southern California indicate that the concentrations of the nitrogen dioxide vary considerably from point to point. On occasions, this variation can approach a factor of 5 in the vicinity of freeways. Thus, the advantage of the long path instrument for measuring average values was demonstrated.

Field tests in the vicinity of a southern California freeway showed that nitrogen dioxide concentration changes of the order of several hundred ppb can take place within a few minutes on the freeway. Tests to the side of the freeway indicate that concentrations a few hundred yards from the freeway are lower by a factor of three to five.

Field tests in southern California conducted with the airborne monitor indicated that while useful qualitative values may be obtained, the operation of the aircraft was severely limited by low visibility which was often below 2 miles and prevented the aircraft from taking off. Aerosol scatter and optical dilution by the California smog enahanced the amount of backscattered radiation returned. to the spectrometer from the upper layers within the inversion. Hence, this radiation contained little or no signal modulation resulting from NO_2 close to ground level. Consequently the spectrometer was saturated with light which represented backscatter from approximately a few thousand feet of atmosphere immediately below the aircraft. This atmospheric backscatter is a function of many complex inter-relating variables, such as solar zenith angle, spectral wavelengths used, particulate (mie) and molecular scattering, field-of-view of the spectrometer etc. Notwithstanding these limitations peculiar to this work in California, we could delineate gas clouds and follow their movement along wind trajectories and also obtain integrated gas profiles which do have meaningful significance.

Section 2

INTRODUCTION

2.1 GENERAL

This final report has been prepared by Barringer Research Limited for the United States Department of Health Education and Welfare under contract No. PH-22-68.

In essence the contract called for a series of field studies involving various configurations of a new measurement technique, a commercial analyzer and a wet chemical referee method. The ultimate aim of the contract was to use the new measurement technique to obtain air pollution measurements for SO_2 and NO_2 under dynamic conditions heretofore unobtainable with conventional instrumentation.

The Barringer technique of correlation spectrometry is a new powerful method for qualitative and quantitative measurements upon a gas, in which an absorption spectrum is cross-correlated in real time against the spectral replica of the species sought. Barringer's development of several instruments utilizing this principle of analysis in various modes of sampling provided the opportunity to study specific questions on the comparisons of in-stack to remote-stack sampling techniques and for long-path to point sampling techniques in air pollution measurements. This report deals only with measurement of SO_2 and NO_2, two gases of immediate interest in air pollution studies. The field studies involved the measurement of SO_2 and NO_2 (as total oxides of nitrogen) both in boiler flue gases and in urban atmospheres. In the stack emission studies comparisons were made between simultaneous in-stack measurements in the breeching of a boiler, remote measurements at the chimney exit and wet chemical analyses of the flue gas. Airborne measurements downwind of the stack, were made to follow the conversion of NO to NO_2. In the urban atmospheric NO_2 and SO_2 studies, comparisons were made between a point sampler, a long path sampler using path lengths of up to 1400 meters, commercially available conventional analyzers and wet chemical referee analyses.

2.2 INSTRUMENT TECHNIQUES

The basic concept of correlation spectrometer has been incorporated in the following types of instruments developed by Barringer Research Limited, namely:

(a) In-stack monitor.
(b) Remote Stack monitor.
(c) Point sample ambient monitor (PSAM).
(d) Long Path ambient monitor (LPAM).
(e) Remote sensor for airborne operation.

The instrumental technique of correlating the incoming spectra against a stored replica is similar in each instrument listed above. The essential differences are in the method of achieving this spectral correlation and the mode of obtaining the operation measurements.

In the in-stack monitor the optical path of the spectrometer is contained in a short probe which is introduced directly into the breeching or stack. This provides a continuous real time measure of the flue gas constituents passing by the probe and eliminates the need for cooling, drying or preconditioning the flue gas. A light beam is projected along the probe and reflected off a mirror within the probe to return to the spectrometer housing located outside the stack. The slot in the probe through which the flue gas passes is 1/4 meter in length and the effective optical path length (2 pass) is 1/2 meter.

The remote stack monitor is a passive telescopic spectrometer using sky light as an energy source. It is used for measuring the gas content of plumes and clouds at the exit of a chimney stack by scanning the field of view and measuring the signal increase recorded through the plume. The plume measurement is compared with the no-gas reading obtained from the sky background at either side of the plume.

The point sample ambient monitor physically draws into a two pass 1.25 meters sample cell the ambient air under measurement. It has an active light source which projects a light beam through the sample cell. The threshold sensitivity of the PSAM is close to 10 ppb.

The long path ambient monitor uses a correlation spectrometer boresighted onto an active light source positioned at any distance up to a maximum of 1400 meters from the spectrometer. This forms the long optical light path and thereby allows the spectrometer system to measure very low average concentrations over this path. For a pathlength of 1400 meters the instrument threhold sensitivity is 1 ppb.

The airborne monitor is a high sensitivity passive spectrometer mounted in an aircraft with facilities for upward and downward looking measurements. If the aircraft is flown above the inversion layer, one can reasonably assume that no gas is present above the aircraft. Consequently an upward looking reading was used for a zero reference. However, more exact zeroing can be achieved using other methods that were not available at the time of this contract. A measure of the total gas burden below the aircraft can thus be made by comparison of the upward (zero gas) and downward looking readings. The instrument can also be used for the remote measurement of plumes and gas clouds from changes in the vertical burden recorded as the aircraft flies over the plume or gas cloud. It should be noted here that since these airborne measurements were made, significant advances have been perfected in instrumentation and technique which negates the need for a sky zero and which is much less susceptible to spectral distribution errors).

2.3 CONTRACTUAL REQUIREMENTS

The contract called for the execution of six experiments as follows:

(1) PHASE I - Stack SO_2 Emissions
A comparison of instack sampling and remote (stack exit) sampling using a standard wet chemical method as reference in measuring SO_2 in the flue gases from coal and oil fired furnaces. This was to be performed under a variety of furnace operating conditions and for different environmental background illuminations.

(2) PHASE II - NO_2 Plume Chase

An experiment involving the airborne surveillance of the exhaust plume from a large power station. The measurements were to be made downwind to determine the rate of formation of nitrogen dioxide from the nitric oxide emitted by the stack.

(3) PHASE III - Ambient SO_2

An intercomparison between point sampling and long path sampling of SO_2 in an urban atmosphere. The comparatively new technique of correlation spectroscopy enabled long path integrated measurements to be made for the first time. The object was to obtain a basic understanding of the relationship between a long integrated path of Ambient SO_2 and measurements of SO_2 at a point in the ambient air.

(4) PHASE IV - Ambient NO_2

A group of three experiments carried out in southern California to obtain data on the concentration of NO_2.

Part A - similar to Phase III but for NO_2 and with vertical distributions determined by airborne measurements at various selected altitudes.

Part B - intercomparisons of NO_2 levels over a freeway and off freeway using integrated long path
- vertical distribution from airborne instrument
- point sampling at various points along freeway
- wet chemical measurements along freeway

Part C - repeated airborne flights over a wind trajectory at a constant altitude using the airborne method synoptic profiling to show the build-up and degradation of NO_2 concentrations with time and location.

Section 3

PHASE I

3.1 OBJECTIVES

The objective in Phase I is to compare the results from the in-stack monitor with data from the remote sensor for typical industrial stacks. Among the variables to be included in this series of tests are the use of coal and oil-fired furnaces burning high and low sulphur fuels and producing flue gases of variable aerosol content. Measurements are to be carried out also under a variety of sky conditions to include varying degrees of cloud cover from clear to total overcast. The Shell wet chemical method is to be used as a reference. A series of simultaneous measurements conducted by DHEW personnel using the Dalmo Victor IR remote sensor were also planned.

Serious difficulties were encountered with the in-stack instrument and in interpreting the readings of the remote sensor early in the program and work on Phase I was discontinued pending results of investigations. Phase II, III and IV were then accomplished and Phase I was then repeated. This section includes some data from the original Phase I and all data from the repeat of Phase I.

3.2 INSTRUMENTATION

The following is a brief description of the in-stack monitor and remote sensor. For a more complete discussion of design and operational features refer to references 1 and 2.

3.2.1 In-Stack Monitor

The correlation stack monitor is a relatively low sensitivity instrument built to withstand dust, heat, corrosion and vibration. The maintenance of optical alignment in the presence of intense thermal gradients proved to be a major problem in its development. Designs have now been evolved which obviate the necessity for a temperature controlled compartment for the optical components as was originally found necessary. The instrument is now capable of being bolted directly to a high temperature duct with negligible affect on instrument performance. (Figure 3.1).

The probe forms a part of an integral package with the spectrometer, light source, and control electronics. (Figure 3.2). The unit is designed for single-hole mounting on the wall of the breeching with the probe inserted into the gas flow. The probe which is about 15 inches long carries a mirror at the far (in-stack)end. This mirror is protected from particulate fouling by an air curtain provided by an external blower. The one-half meter (2 pass) optical absorption path length is defined by the air curtain which protect the optical train from the hostile environment.

The use of a one-quarter meter of sample length (i.e. 1/4 meter slot) is based on the assumption that the gas mixture across the stack is homogenous with respect to the gaseous constituents. This had induced some scepticism, presumably due to the necessity for accurate isokinetic sampling across the whole area of the duct when measuring particulate matter. A series of wet chemical traverses carried out by York Research Corporation at Stamford, Connecticut hower, has confirmed our belief that there is no significant stratification or uneven distribution of gaseous components across the flue diameter.

The in-stack instrument was tested for stability and temperature sensitivity in an environmental test chamber within the range from -10° to +100°C. The environmental limitations of the current probe design are temperature, pressure and sensitivity. The probe is presently rated for use at up to 800°F, and will probably be suitable for operation up to 1000°F. The pressure limitation arises from the fact that the blower for the air curtain works against the pressure inside the flue. The upper pressure limits of 10 inches W.G. is set by the size of the blower but where palnt air is available this limit could be relaxed.

The solid state electronic unit follows standard coherent detection practice and the signal from the spectrometer is fed to an A.G.C. circuit to compensate for changes due to lamp intensity and dust loading. After band-limiting amplifiers, the signal is fed to a synchronous detector where it is gated with a signal from the reference photomultiplier. A low pass filter drives a standard 100 mv potential recorder which can be calibrated in parts per million.

The in-stack monitor used for the initial Phase I work used a quartz prism for dispersion of the light beam and vibration was effected by means of a torque motor driving a diffractor plate situated just behind the entrance slit. Calibration of the instrument was carried out by means of an optical cell which could be inserted through the slots in the probe (referred to herein as a "slot cell") into which known amounts of SO_2 could be injected. For routine checking of the instrument sensitivity in the field, a one centimeter reference cell of known gas content can be inserted into the optical path. The Phase I repeat program used an improved version of the stack monitor in which the quartz prism was replaced with a diffraction grating, correlation was then achieved by vibrating the grating upon its torsion bar mount by means of a torque motor.

3.2.2 The Remote Sensor

The remote sensor (Figure 3.3) operates in a passive mode, utilizing the background sky as the light source. Spectral correlation is achieved by vibrating refractor plates mounted on the tine of a tuning fork as shown in Figure 3.4. This instrument when used as a remote sensor enables the quantity of gas within the field of view to be determined. Zeroing is performed by looking to either side of the target plume and adjusting the instrument output to a convenient reference value. For routine sensitivity checks and calibration in the field, the instrument is equipped with two 1 cm fused-silica reference cells, (as shown in Figure 3.4) which can be easily inserted into the optical path either singly or together while sighting on the sky background to one side of the plume. The instrument is then sighted on the plume and the signal generated as a result of

SO_2 in the plume is recorded.

Because of the generally rapid mixing of flue gas with ambient air following emission at the stack exit, the field of view of the instrument is usually closed down so as to observe only a small section of the central portion of the plume as near the stack exit as possible. The horizontal path length through the plume (assuming a vertical plume) is then assumed equal to the internal diameter of the stack.

3.2.3 Wet Chemical Reference

The primary wet chemical method used in Phase I was the Shell Thornton procedure intended specifically for the determination of SO_2 and SO_3 in stack gases. A detailed description of the method is given in Reference 3. The essential feature of this technique is the analysis of flue gases for sulphur oxides by oxidizing the dioxide to the sulphuric acid which is determined by titration. The determination of the proportion of the two oxides poses some problems because of the ease with which the dioxide is converted to sulphuric acid, especially in the presence of the calatylic metal oxides which are present in fly ash. The Shell-Thornton method uses a short heated silica probe to bring out the flue gases while still above the dew point, into an isopropyl alcohol bubblers which removes the sulphuric acid aerosol and effectively prevents oxidation of the sulphur dioxide. A second bubbler containing hydrogen peroxide traps the sulphur dioxide by oxidizing it to sulphuric acid. After a suitable sample has been collected - a procedure requiring about 20 minutes - a flow of purified air is drawn through both bubblers to transfer any sulphur dioxide trapped in the first bubbler into the second bubbler. The acid contents of both bubblers are then determined by titration.

During the earlier part of the Phase I programme the Shell-Thornton method (abbreviated "Shell" hereafter) was supplemented with the simpler Reich method. This latter technique, based on the decoloration of iodine, can be accomplished in about three minutes as compared with 20 minutes for the Shell. This is an advantage in investigating short term fluctuations in gas concentrations. It is important to note that while the Reich test was used in conjunction with the Shell test it was not used to replace the Shell procedure. Also the experience gained on this programme over a large number of simultaneous measurements showed that the average of a series of Reich tests agreed closely with the Shell results with discrepancies usually less than 5%.

3.3 EXPERIMENTAL APPROACH

A number of different boiler installations were chosen to satisfy the contract requirements for both oil and coal fired sources. These installations were:

(1) Gulf Oil Refinery - Clarkson Ontario, Boiler No. 5 and CO Boiler
(2) Ontario Hydro Lakeview Generating Station, Toronto, 300 Megawatt units No's 3, 4 and 7, 8.
(3) Lever Brothers - Toronto, process steam at 100,000 lb/hr, oil fired.

In all cases the experimental techniques developed early in the Phase I programme were used throughout (with the exception of the Gulf CO Boiler) and involved the installation of the in-stack correlation spectrometer in the breeching near the base of the stack. The wet chemical sampling probe was installed in close proximity to the spectrometer probe. The remote sensor was tripod-mounted and transported by a mobile vehicle.

In general the experimental procedure followed was to continuously monitor the SO_2 concentrations in the breeching with the spectrometer probe while taking repeated samples of flue gas with the wet chemical system. Concurrently, measurements of the flue gas were made at the stack exit using the mobile remote sensor. To obtain a measure of the effect of atmospheric scattering on the remote sensor measurement, a series of remote sensor readings were taken at different distances from the stack. When feasible each series of readings was taken with the angle subtended at the stack by the sensor and the sun held roughly constant. It was not feasible to vary the fuel sulphur content or alter combustion conditions at these production facilities in a programmed fashion. Consequently the duration of the experimental period was extended to obtain as wide a range of SO_2 concentrations and dust loadings as was practicable as a result of normal fluctuations in the fuel sulphur content, fuel burning rate, excess air and from periodic purging of soot accumulations. On occasions large changes in SO_2 level were obtained. At the Lever Brothers oil-fired test site this was achieved by releasing SO_2 directly into the boiler inspection door from a portable high pressure container. At the coal fired test site (Lakeview) this was achieved by monitoring flue gas while the turbine generator system was undergoing a series of special tests. The test period for both oil and coal buring sources were of sufficient length to obtain remote sensor plume results over a wide range of sky, wind and visibility conditions.

Whenever possible, the timing of the wet chemical samples, spectrometer probe calibrations and remote sensor set-ups were coordinated so as to permit a meaningful comparisons of the measurements. The following discussion of the work performed is presented in chronological sequence and describes the identification and investigation of problem areas which revealed themselves during the early stages of the Phase I program and treats in considerably greater detail the work performed and results achieved during the Phase I continuation period. Since the earlier stage of Phase I was basically a trouble shooting and investigation period and the later part of Phase I was entirely a data gathering and data analysis period, these two periods are presented in two parts as Phase I (Part 1) and Phase I (Part 2).

3.4 PHASE I (PART I)

3.4.1 Gulf Oil Refinery, July 1968

Our first field work was undertaken at No. 5 Boiler of the Gulf Oil Refinery, Clarkson, Ontari, which exhausts through a single stack. The in-stack monitor was initially aligned and calibrated in the BRL laboratories and then mounted on the breeching of this boiler. The remote sensor was set up to view the stack's exit. This boiler is equipped for both oil and gas firing, the preferred fuel being natural gas which is used exclusively during the summer. The oil fuel is residual oils with 3% sulphur or slop oils of unknown and highly variable composition. During this initial testing program some of the burners were using oil and the remainder natural gas.

To create variations in the SO_2 content of the flue gas, the number of oil and gas burners in operation at any given time were varied. To meet the contract requirements of varying plume aerosol content, it was planned to generate #2 Ringleman smoke by adjusting the fuel/air ratio and by manipulation of the dampers. Moreover attempts to regulate the plume by adjusting the fuel/air ratio were unsuccessful because of automatic controller action and only short periods of very dense smoke resulted. Since the exit velocity of the stack was less than 10 ft/sec, even very light winds resulted in a stretched and turbulent horizontal plume. Consequently our field work was considerably complicated by the above effects.

After review of the initial data obtained at this site marked disagreements between the Shell results and the in-stack monitor were apparent. The degree of disagreement was shown to be a direct function of the flue gas temperature.

Errors in the remote sensor measurements were also apparent. These were found to stem from two causes; the extremely low stack exit velocity and atmospheric scattering. In general, the remote sensor results were lower than the Shell values and showed particularly low values when conditions of low visibility or dense smoke occured.

3.4.2 Lakeview Generating Station

A similar series of exploratory tests were conducted at the No. 3 generating unit of the Ontario Hydro Lakeview Generating station whose location is shown in Figure 3.5. This station has four stacks which are five hundred feet high and each stack serves two 300 Mwatt generating units. The in-stack unit and Shell probes used existing sampling ports and staging. The Lakeview plant employs a pulverized coal fueled system and 2.2% sulphur coal which generates about 1400 ppm SO_2. The grade of coal is substantially constant and stock-piling is carried out in such a manner as to ensure mixing of various batches. It was therefore not possible to alter the fuel sulphur content neither could the boiler operating parameters be changed to make smoke.

The results of these tests confirmed the temperature dependency of the in-stack monitor and indicated that the problem was not associated with the use of oil fuel. Because of the relative constancy of the Lakeview plume characteristics, firm identification of the atmospheric scattering problem associated with the remote sensor was possible.

3.4.3 Investigations

In order to investigate the cause of the temperature dependency problem of the in-stack it was transferred to a new test site at Humberview, Toronto. The Humberview test facility is a laboratory established by the Department of Public Works of Metropolitan Toronto to study dust emissions from various types of incinerators. In summary the most important results of these investigations was the replacement of the quartz prism dispersing element with a grating element and the calibration of the instrument to take into account the change in sensitivity of the in-stack monitor due to temperature-induced line broadening of the SO_2 absorption spectrum. The line broadening effect, termed the "modulation factor", was measured over the operating temperature range of the instrument and is reproduced in Figure 3.6 The use of the modulation factor appropriate to the flue gas temperature of a given installation is required to obtain accurate quantitative results. One can see from Figure 3.6, that when the modulation factor ranges from 1 to 3, the latter occuring when the gas temperature approaches 800°F. Correction also has to be made for the usual gas low density changes associated with the flue gas temperature changes. As a percentage error this is simply the ratio of in-stack temperature to the outside ambient temperature. For example the Lakeview Station stacks were at 300°F, giving a temperature correction of about 15%.

Concurrent with the in-stack spectrometer investigations at Humberview, a theoretical study of the atmospheric scattering and range dependency problem of the remote sensor was conducted. The major part of these investigations and the associated field test results are covered in detail in reference 4, and will be reviewed only briefly. In summary the study showed that significant light scattering can occur between the plume and the remote sensor which will cause a reduction in the sensor's sensitivity was shown to be a function of the atmospheric turbidity and the distance between the stack and the sensor. Table 3.1 presents test results obtained from both Gulf and Lakeview stacks during August 1969 while Table 3.2 provides their analyses. The percentage errors quoted in Table 3.2 are calculated using the Shell measurement as the reference and the remote sensor measurement is the average integrated value over the same time period that the Shell measurement was made. These data show the effect of slant range and visibility on the accuracy of the remote sensor measurement. It is obvious from these tables that minimum scattering error occurs at minimum range during times of good visibility. The last two columns of Table 3.1 are shown plotted in Figure 3.7. This curve shows that in spite of errors associated with estimating visibility and the fact that the data was obtained at a meteorological station several miles from the test sites, there is a close relationship between the ratio of range/visibility and the error in the remote sensor measurement.

TABLE 3.1

REMOTE SENSOR RESULTS AT GULF AND LAKEVIEW STACKS, AUG./SEPT. 1968

Date 1968	Stack	Slant Range (ft.)	Visibility (miles)	Weather	Remote Sensor (ppm)	Shell (ppm)	Ratio Shell/Remote	Ratio Visibility/Slant Range
Aug. 12	Gulf	580	15+	Clear	280	250	0.9	26+
13	Gulf	580	8	Hazy	460	935	2.03	13.7
14	Gulf	580	15+	O'Cast	220	250	1.13	26+
15	Gulf	700	15+	Clear	350	450	1.30	22+
15	Gulf	700	15+	Clear	420	655	1.55	22+
28	LV	1250	15+	Clear	400	1385	3.46	12+
29	LV	1250	12	Clear	555	1330	2.40	9.6
Sept. 12	LV	1250	15+	Clear	725	1450	2.00	12+
12	LV	1250	15+	Clear	650	1390	2.14	12+
18	LV	1600	3	V Hazy	185	1360	7.35	1.8
18	Gulf	700	3	V Hazy	175	570	3.25	4.3
19	LV	1600	8	o'cast	330	1300	3.94	5.0
19	Gulf	350	8	o'cast	240	500	2.09	14.5
20	LV	1830	8	Hazy	325	1105	3.40	4.3
20	LV	1450	6	Hazy	245	1115	4.57	4.1

TABLE 3.2

	Range (ft.)	Weather (Condition, visibility) in miles	Error $(\frac{\text{Remote-Shell}}{\text{Shell}} \times 100\%)$
(1) Very Short Range			
	350	overcast 8	-52
(2) Short Range			
	580	clear 15+	+12
	580	overcast 15+	-12
	580	Hazy 8	-51
(3) Medium Range			
	700	clear 15+	-22
	700	clear 15+	-36
	700	v. hazy 3	-69
(4) Long Range			
	1250	clear 15+	-76
	1250	clear 15+	-50
	1250	clear 15+	-58
	1250	clear 12	-58
(5) Very Long Range			
	1450	hazy 6	-62
	1830	hazy 8	-70
	1600	hazy 8	-75
	1600	v. hazy 3	-86

The theoretical treatment of the scattering problem described in Reference 5, showed that extrapolation of a curve defined by a series of remote sensor measurements taken at different ranges could be used to largely compensate for the scattering errors associated with measurements obtained at any one range. Figures 3.8 and 3.9 show the results of several experiments at the Gulf Oil CO Boiler in which extrapolation to zero range was used to arrive at stack exit concentrations. The Gulf CO boiler is a gas-fired unit burning sulfurous gases and was used for this particular experiment because of its high exit velocity and well defined plume in moderate winds. Figure 3.10 shows similar results for the Lakeview stack.

3.4.4 Gaseous Reactions Within A Stack

As a result of the continued low readings obtained with the remote sensor, it was suggested that significant amounts of sulphur dioxide could enter into chemical reactions, e.g. calatytic oxidation to sulphur trioxide, so that the gases issuing from the stack contain much less sulphur dioxide than is measured at the breeching. This could be a mjaor source of error in the 500 ft. stacks at Lakeview.

By arrangement with the Ontario Hydro, who had a steeple jack working on the top of one of the chimneys, simultaneous chemical measurements were made at the top and bottom of the stack. The boilers feeding the stack were kept on a steady load for the duration of the test. The sulphur dioxide level in the flue gas was established by means of Shell determinations before and after the tests at the top of the stack. During the tests at the top of the stack, the constancy, of the SO_2 input at the bottom was monitored by the In-stack Monitor, which showed a slow increase in SO_2 during the progress of the tests. The Shell-Thornton results were:

Sample 1	Bottom	at 0906-0922 hr.	1105 ppm
2	Top	at 1225-1245 hr.	1085 ppm
3	Top	at 1440-1500 hr.	1115 ppm
4	Bottom	at 1630-1650 hr.	1355 ppm

These results confirm that there is no significant reaction resulting in the removal of sulphur dioxide during the passage up the stack.

3.4.5 Conclusions

To sum up the results of Phase I (part 1) it may be stated that:

(1) Difficulties were encountered in the measurement of in-stack flue gases because of two basic reasons;

  (a) broadening of SO_2 absorption bands and consequent loss of instrument sensitivity was not compensated for, and

  (b) Instability of the in-stack monitor optical system resulting from thermal distortion of the quartz prism produced substantial errors.

(2) Difficulties were encountered in the measurement of stack gases as the exit because,

  (a) loss in sensitivity due to atmospheric scattering was not compensated for, and,

  (b) the very low exit velocity resulted in large negative errors with considerable scatter in the data.

(3) The in-stack monitor was modified to improve its temperature stability and the temperature modulation factor was measured and an appropriate calibration curve drawn up.

(4) The physics of atmospheric scattering and its effect on the remote sensor were examined and techniques developed to permit the effects of scattering to be compensated for.

The accomplishment of the Phase I (Part I) programme established a firm basis for proceeding with Phase I (Part 2).

3.5 PHASE I (PART 2)

3.5.1 Installation

Because of the limitations of the Gulf Refinery facilities in terms of the program requirements, arrangements were made to conduct tests at the Lever Brothers plant in south Toronto.

Figure 3.11 shows a plan of the Lever Brothers plant. The boiler house generates process steam at the rate of 100,000 lb/hr for the manufacture of soaps and detergents. It is equipped with three independent oil-fired boilers, two of which are in use at any given time. Figure 3.12 illustrates the arrangement of ducts and the probe installation. Boilers No. 1 and 3 were working near full load over the duration of the test period while Boiler No. 2 was shut down. The spectrometer probe and wet chemical sampling probe were both installed in the flue of boiler unit No. 1. Since the steam load is evenly balanced between units 1 and 2 and fuel and combustion conditions are virtually identical, the SO_2 concentration in the flue gas of unit No. 1 was assumed representative of the SO_2 level in the combined output of units 1 and 3. It was not feasible to measure the combined effluent in the stack itself because of the lack of sampling ports and the presence of a baffle in the stack which prevented mixing of the outputs of units 1 and 3 until reaching a point in the stack well above the roof level. Although Boiler No. 2 was shut down and its damper closed there was still a substantial free flow of air reaching the stack through flue No. 2 under conditions of natural draft. For purposes of comparing the in-stack results with the remote sensor measurements, the mass flow of both flue gas and clean air was measured by means of velocity and temperature traverses in all three flues and the effect of dilution of the stack exit readings allowed for.

Figure 3.13 shows the completed installation including the Shell sampling unit. The fuel used was Bunker "C". The analysis is as follows:-

specific gravity @ 60°F	0.9767
water (by volume)	0.05%

sediment	0.06%
ash	0.07%
sulphur	1.82%
BTU/Emp. Gal. @ 60°F	179,400

Figure 3.14 shows the truck mounted remote sensor viewing the Lever Brothers stack. This photo was taken from remote sensor site P5 of Figure 3.11.

3.5.2 Flow Measurements

Velocity head traverses were made across each flue using a pitot tube and inclined manometer at each port location shown in Figure 3.12. The data obtained are as follows:-

#1 Flue

	(ins W.G.)	°F	°A (Fahrenheit units)
Head	1.0	340	800
	1.2	350	810
	1.3	360	820
	1.2	350	810
	1.3	350	810
	1.1	350	810
	1.0	350	810

Area = 4' x 4' = 16 sq. ft.

Av. Temp. = 810°A
Av. Lead = 1.2"

Velocity = 80 F.P.S.

Flow = 76,800 C.F.M.
= 49,920 S.C.F.M. (70°F)

#2 Flue

	(ins W.G.)	°F	°A (Fahrenheit units)
Head	0.35	80	540
	0.35	80	540
	0.4	80	540
	0.5	80	540
	0.4	80	540
	0.4	80	540
	0.4	80	540

Area = 4' x 4' = 16 sq. ft.

Av. Temp. = 540°A
Av. Head = 0.4"

Velocity = 40 F.P.S.

Flow = 38,400 C.F.M.
= 37,632 S.C.F.M. (70°F)

#3 Flue

The traverse in this case showed the flow in this flue to be the essential same as that in flue No. 1.

Dilution of the flue gas by clean air is then:-

total flue gas from #1 & #3	= 99,840 SCFM
by pass air from #2	= 37,632 SCFM
Total gas in stack	= 137,472 SCFM

SO_2 is diluted by clean air in the ratio $\frac{99,840}{137,472} = 0.726$

To compare the stack exit measurements with the Shell or in-stack values the remote sensor results are multiplied by 1.38.

3.5.3 PROCEDURES

As mentioned previously whenever possible all measurements were conducted in a coordinated fashion to maximize the significance of comparisons. Since the Shell method was the reference and took the longest to perform, both the in-stack and remote units were usually calibrated, adjusted, or moved as necessary during the down-time intervals of the Shell measurement. In general the Shell samples were taken as frequently as the technique would permit over each day of data gathering.

The in-stack unit was generally left in continuous operation once the day's data run had begun and was removed from the flue only occassionally to check the zero level and instrument sensitivity.

To accomodate the variations in wind direction and sometimes to avoid interference from neighbouring plumes, remote sensor sites were chosen on three sides of boiler house as shown in Figure 3.11. In conducting a series of multi-range measurements the remote sensor used sites which lay roughly in line with the stack e.g. P7, P2, S5, S2, S3 and S4 and moved from one site to next as quickly as circumstances would permit.

To provide more continuous data for comparison with the continuous in-stack monitor data, the remote sensor was stationed at the nearby sites e.q. P.5 P7 or P.4. In these positions the remote sensor results generally corresponded closely with the in-stack readings without any need for correction due to scatter except during periods of rain fall.

After installing the equipment and conducting a series of trial runs on Sept. 29th and 30th, 1969 the first of a series of daily continuous data runs began on Oct. 1st.

3.5.4 RESULTS - Oct. 1st/69

For the Oct. 1st 1969 run, the remote sensor was stationed for the full day at P5. Figure 3.15 shows a portion of the in-stack chart. The fluctuations of flue gas (SO_2) density is apparently typical of boiler/fan installations of this type. The reference cell was an external 1/4 meter cell containing the equivalent of 500 ppm SO_2 at 70°F and one atmosphere. For each calibration the reference cell was flushed with clean air and injected with 0.2 ccs of SO_2 at ambient pressure and temperature.

A typical calculation for SO_2 concentration in the flue gas is performed as follows:

$$SO_2 \text{ (ppm)} = \frac{D_1}{D_2} \times 500 \times \text{Mod. Factor} \times \text{Temp. Factor}$$

where: D_1 = Target gas deflection = 42 chart div.
D_2 = Ref. Cell deflection = 48.5 chart div.
Mod. Factor= 1.45 from Figure 3.6 @ 300°F (149°C)

$$\text{Temp. Fact.} = \frac{\text{Flue Gas temp.}}{\text{Ambient Temp.}} \qquad \text{Ambient Temp.} = 21^\circ C$$

$$= \frac{273 + 149}{294} \qquad = 294^\circ A$$

$$= 1.43$$

$$\text{Therefore } SO_2 \text{ (ppm)} = \frac{42}{48.5} \times 500 \times 1.45 \times 1.43$$

$$= 898 \text{ ppm}$$

The purpose of the modulation factor was discussed previously. The temperature factor takes into account the Charles Law expansion of the gas. This is required since the sensor is actually responsive to the density of the SO_2 component of the flue gas and uses a reference cell which has been calibrated in terms of concentration (ppm by volume) at 21°C and 760 mm. Hg. The slight negative pressure in the flue has a negligible effect on the measurement and pressure correction is not necessary.

Figure 3.16 shows a portion of the remote sensor chart. V_1 and V_2 are the responses obtained from the reference cells while observing the sky to one side of the plume. V_T is the response from the plume itself. These measurements were made at station P_5 at 1004 EST.

The SO_2 concentration in the plume is found from the following expression:

$$\frac{1}{C_T L_T} = \left[\left(\frac{\frac{1}{C_1 L_1} - \frac{1}{C_2 L_2}}{\frac{1}{V_1} - \frac{1}{V_2}} \right) \left(\frac{1}{V_T} - \frac{1}{V_2} \right) + \frac{1}{C_2 L_2} \right] \times \left[\frac{273 + T_s (^\circ C)}{293} \right]$$

where V_1 = NO. 1 ref. cell rdg. (low value) volts or chart div.
V_2 = No. 2 ref. cell rdg. (high value) volts or chart div.
C_1L_1 = No. 1 ref. cell calibration constant ppm-meters
C_2L_2 = No. 2 ref. cell calibration constant ppm-meters
V_T = Target gas delfection volts or chart div.
T_s = stack exit temperature
L_T = Depth of target along line of sight meters
C_T = Concentration of SO_2 in target plume ppm

Note that in the case of the remote sensor it "looks through" the total diameter of the gas column and therefore must cope with a much greater ppm-meter product than does the in-stack unit. Since for very large ppm-m values, the sensor response is inherently non-linear, two reference cells are required. For full details of the remote sensor method refer to Reference 2 Processing of the remote sensor data begins with transferring the chart data to a convenient data sheet such as shown in Table 3.2 / 3. This table contains all data pertinent to the remote sensor measurement. Meteorological data were obtained from the records of the Toronto Island Airport and plume characteristics were noted at the time of measurement. Note that in the case of a bent-over plume the sensor station was always chosen so that the sensor's line of sight intercepted the plume axis at approximately 90°. The "look-up" angle of the sensor i.e. the inclination of the line of sight was measured with a hand-held Abney inclinometer. The precision of this measurement is about 10 minutes of arc. The aperture refers to the setting of the sensor vertical field of view as determined by the vertical height of the entrance slit. This setting is read on a dial which has a nominal scale of 3.7 milliradians/turn. Therefore a setting of 0.5 turns = a vertical acceptance angle = 1.85 mR. At a slant range = 126 meters the vertical F.O.V. = 0.23 meters (0.75 ft.). The width of the entrance slit is fixed and the azimuth acceptance angle is a constant 3 mR. The F.O.V. at 126 meters is therefore 0.378 meters (1.24 ft.) wide x 0.23 meters (0.75 ft.) high, i.e. in the case of a cylindrical plume of diameter 2.6 meters and a range of 126 meters, the sensor, when pointed for peak response, observes only the central portion of plume with a F.O.V. no greater than 1/7th of the full plume diameter.

The A.G.C. (Automatic Gain Control) voltage is a measure of the ultra-violet flux reaching the sensor. Referring again to Figure 3.16 note that an AGC performance check was made using a 10% transmission neutral density filter. The fact that the presence of the filter in front of the entrance window did not induce error but only caused an increase in the noise pattern demonstrates that there was more than an adequate light level available for the measurement. With a 90% reduction in incident light level the AGC level rose to 6.4 volts. The limiting value is 7.0 volts.

The optical pathlength through the plume is shown at X_{LT} in Table 3.3 and was obtained from

$$X_{LT} = \frac{W_s}{\cos \alpha}$$

where W_s = stack internal diameter = 2.6 meters

α = lookup angle

X_{LT} is equivalent to L_T in the remote sensor equation previously discussed.

Distance between the sensor and the stack exit is termed slant range R_s

and $$R_s = \frac{\text{stack height } (H_t)}{\sin \alpha}$$

For purposes of comparison with the instack measurements, the remote sensor result is shown as two values, one which is the measured concentration at the stack exit and the other which is the stack exit value multiplied by the clean air dilution factor of 1.38. After tabulating the raw chart data in this form, the tabular data are fed into a computer program which solves the foregoing equations for F.O.V., XLT, R_s and C_T, the target gas concentration.

The results of the in-stack measurements and stack exit concentrations compensated for clean air dilution are shown plotted along with the Shell averages in Figure 3.17. The in-stack and remote sensor points are two-minute averages. Both instruments have a response time of about 3 seconds. The Shell results are averaged over a 15-20 minute sampling interval and are shown as a horizontal bar in Figure 3.17. Note that the remote sensor data tend to have greater scatter than the in-stack data. The reason for this is due mainly to plume fluctuations and to a lesser extent possibly by incoherent fluctuations in burning rates of the two boilers.

The in-stack and remote sensor data of Figure 3.17 were examined for correlation and regression using the IBM Quicktran Common Library Program, with the following results: (IBM STATPK)

Correlation Coefficient.......	0.89
Regression....................	0.97
Intercept.....................	73.66

It is apparent that a high order of agreement exists between the in-stack unit and the remote sensor particularly in view of the differences in the two methods of measurement. The first Shell test was some 75-80 ppm lower than the in-stack result but was in very close agreement on the two subsequent tests. The regression or slope of 0.97 indicates that the calibration of the two sensors were almost identical and the intercept of 73.66 indicates a minor discrepancy in determination of the zero level.

The abrupt drop in signal and rapid recovery at time 1110 on Figure 3.17 was due to purging of soot accumulations in the boiler tubes, a daily routine of the boiler operator. This results in a particularly dense cloud of yellow-brown to black smoke of short duration.

It is significant that the results of Figure 3.17 were achieved with no correction for atmospheric scattering. This is no doubt due to the short slant range used and the good visibility. The small loss of signal due to scattering was at least partially compensated for in assuming the stack exit temperature to be the same as the flue gas temperature (300°F). No correction was applied for temperature drop due to dilution air or to stack losses.

An interesting side-light of the day's run was the negligible effect observed when the fuel-oil additive used in the Lever furnaces was turned off for a 3½ hour period. Fuel additive is composed of finely divided oxides of magnesium and aluminum suspended in a light carrier oil and is blended with the fuel oil in the ratio of 1 gal. of slurry to 1500 gal. of fuel oil. It was turned off during the data run in the hope that it would have a significant effect on the SO_2 content of the flue gas. The fact that its effect was negligible is because the additive is primarily effective in removing SO_3 from the products of combustion, an essential function in its role of inhibiting the buildup of corrosive deposits on the boiler surfaces.

3.5.5 Results - October 2/69

The remote sensor data for this day's run is provided in Table A-1 in appendix A. The in-stack, remote and Shell data is presented in Figure A-1. As shown in Table A-1 sky and visibility conditions for accurate remote sensor measurements were very poor and the fact that surprisingly good results were obtained was due to the light winds and fairly well behaved plume. Low sky brightness is evident in the observations made and the relatively high AGC levels.

The effect of scattering on the remote measurements is clearly evident in Figure A.2. The extrapolation to zero range was performed with the knowledge that the tangent to the curve becomes a horizontal straight line as an asymptote as range reduces to zero. The shape of the lower curve so constructed was transposed to the higher minimum range values shown in Figure A.2 to arrive at stack exit concentrations for these times. These zero range values were then multiplied by the dilution factor and plotted in Figure A.1. The number of remote data points was less than the previous day because of time taken to move from station to station. The in-stack sensor data is also rather sparse and what is shown is probably not very accurate because of inadvertent miss-alignment of the in-stack unit. The remote data agrees with Shell results within about 100 ppm which is considered good in view of the meteorological conditions.

3.5.6 Results - October 3/69

The remote data is provided in Table A-2 the ranging plots in Figure A.3 and the combined data in Figure A.4. The in-stack data is also shown averaged over a sample interval similar to that of Shell. The in-stack and remote data tend to agree with each other more closely than with the Shell.

3.5.7 Results - October 6/69

The remote data are shown in Table A.3 and the combined data in Figure A.5. This was a day of bright but very hazy sky and gusty winds. The pronounced scatter in the remote data points is due to the fluctuating plume, low values by the plume center moving out of the F.O.V. and occasional high values probably due to sudden shifts in wind direction which produced greater pathlengths than the stack diameter. SO_2 was injected into one furnace from a lecture bottle at time 1140 and it was recorded by all three measurements. The Shell values at this time are low because the sampling time exceeded the duration of the SO_2 peak. A second injection at 1350 was also recorded by the three methods. The lack of exact time coincidence in the remote and in-stack data points is very likely due to inexact time observations. Because all data shown in Figure A.5 was obtained at close range stations P5 and P6, scatter correction has not been included.

3.5.8 Results - October 7/69

The remote data are shown in Table A.4 and the combined data including remote from P6 in Figure A.6. These data agree fairly well. The few low in-stack values are due to tube blowing. Following the heavy rain in the afternoon a series of ranging measurements with the remote sensor were performed and the data are shown plotted in Figure A.7. The zero range value of 760 ppm when referred to the flue is 1050 ppm which compares reasonably well with the nearest Shell value of 980 ppm.

3.5.9 Results - October 9/69

Remote data is presented in Table A.5 and combined data in Figure A.8 (a). A particularly interesting feature of this day's run was the injection of 15 lbs. of SO_2 into boiler NO. 1 inspection door. The response of all three measurements are shown quite dramatically in Figure A.8 (a). Copies of the chart profiles are shown in Figures A.9 (a) and A.9 (b) and high resolution plots of the injection interval are shown in Figure A.8 (b). The shell result again is low because of the length of sampling time relative to the duration of the SO_2 peak. The plots of Figure A.8 (b) have been normalized in time by superimposing the prominent peak values. The difference in the height of the profiles in Figure A.8 (b) is not known with certainty but possible reasons could be the effect of the chimney baffle which prevents mixing of the two boiler outputs until a point in the stack is reached well above the roof level. If flue gas flow about this point tends to be laminar then the remote data would tend to be high or low depending on the part of the plume under observation. A second reason could be the lack of well defined remote values just before and just after the injection.

Correlation calculations for the data of Figure A.8 (b) are as follows:

Correlation Coefficient	0.925
Regression Coefficient	1.070
Intercept.........................	129.4

3.5.10 Lakeview Generating Station

Installation plan of the Lakeview station was shown previously in Figure 3.5. Two different instrument installations were used during the program as indicated in the layout sketch of Figure 3.18(a). Figure 3.18(b) shows the in-stack and Shell installation in generator unit No. 7.

Remote sensor ranging experiments were conducted on both stacks #2 and #4 using the stations and traverse lines indicated in Figure 3.5.

Initial tests began with the equipment installed in the breeching of unit No. 3.

As shown in Figure 3.18(a) the location is on the output side of the fan. During the test period generator unit No. 4 was shut down. As a result the hot flue gases from unit No. 3 mixed with clean dilution air which entered the stack via unit No. 4 under natural draft. The dampers in the No. 4 flue were closed as in normal practice but since they do not seal, a very significant flow of dilution air was present during the tests. It was not feasible to measure the flow with acceptable accuracy because of the duct size (5' x 15' approx.) and attempts to obtain approximate values using a standard 3' pitot tube probe were unsuccessful. Remote sensor data obtained under these circumstances i.e. without dilution correction, produced low zero range values. After several days of tests in this location Hydro officials reported operational difficulties with the generator unit and all sensor measurements were discontinued when the unit shut down for repairs.

Because of the extended repair period of No. 3 unit arrangements were made to install the in-stack equipment in the breeching of generator unit No. 7 and all subsequent data runs were conducted in this location. On the three days listed, where measurements were made on generator unit No. 7, unit No. 8 was shut down. Consequently, for the same reasons quoted above, dilution effects were not known.

3.5.11 Results - October 22/69

Figure A.10 shows the in-stack results obtained from an initial data run on generator unit No. 3. A sample of the strip chart is shown in Figure A.11. The Shell average is shown as a horizontal bar extending over the sample interval. The dotted data points were taken off the chart using the appropriate calibration values while the "x" points were obtained by using the same calibration value throughout. There is reason to believe that the calibration performed at 1000 AM was in error causing the data between 1000 and 1200 to be low. Using the afternoon calibration for the morning readings resulted in the higher values and closer agreement with the Shell results.

3.5.12 Results - November 24/69

The equipment was installed in the breeching of generator unit No. 7 for these tests. Table A.6 shows all remote sensor data, Figure A.12 shows the ranging data and Figure A.13 shows the combined data. Meteorological conditions were near ideal for these measurements. Two ranging runs were made as shown in Figure A.12, one in the morning and one in the afternoon. Figure A.13 shows the close agreement achieved between the zero range values and the in-stack results. Figure A.13 also shows a very interesting comparison of data obtained while the No. 7 generator was undergoing special tests. Over the duration of this wide swing in SO_2 levels, the remote sensor was stationed at site S6 thereby permitting continuous remote data to be generated.

In-stack to remote correlation calculations covering the period 1050-1530 and using only S6 remote data, with no allowance for scatter, resulted in the following:

Correlation Coefficient	0.987
Regression Coefficient	1.035
Intercept........................	96.57

The agreement between the two sensors is very close indeed. Shell readings tended to be about 100 ppm high over the entire period.

3.5.13 Results - November 27/69

The remote data are shown in Table A.7 the ranging data in Figure A.14 and the flue profiles in Figure A.15. As indicated in Table A.7 there was continuous moderate snow fall over the duration of the remote sensor measurements. The intent here was to measure the degradation in sensor performance under extreme scattering conditions. Surprisingly enough there was still an adequate ultraviolet flux level to operate although AGC levels were approaching maximum. The effect of extreme scattering is evident in the low zero range determinations of Figure A.14. The curves of Figure A.14 have been extrapolated using the usual rule but under conditions of such heavy scattering additional measurements are required at closer range to better define the curve. Obviously remote sensing in a snow storm is not too profitable. Figure A.15 shows reasonably close agreement between the in-stack unit and Shell.

3.5.14 Results - November 28/69

Remote data is presented in Table A.8, ranging data in Figure A.16 and combined data in Figure A.17. Visibility was good all day but high gusty winds made remote measurements very difficult. Figure A.16 shows the very large scatter in the data caused by fluctuating plume. A reasonably good run was made between times, 1000 and 1100. As the day wore on, gustiness increased and the data became so scattered as to be unusable. The in-stack data in Figure A.17 shows a substantially lower reading relative to the Shell. The cause for this is not known with certainty, but a likely reason was excessive air leakage around the in-stack mounting flange or through the openings in the instrument itself. Since the location of the in-stack unit in generator unit No. 7 was on the inlet side of the fan, the in-stack unit was operating into a negative duct pressure of some 12 in. of water. Excess air flow into the air curtain passages of the in-stack probe results in distortion of the air curtains, reduced optical path length and low readings. Low readings have been traced to this cause on previous occasions.

The remote data presented in Tables A.6, A.7 and A.8 has been re-grouped in Table A.9 to show more clearly the relationships between slant range, weather conditions and percentage error.

3.6 CONCLUSIONS

The results of the Phase I program may be summarized as follows:

(1) The in-stack monitor is capable of accurate measurements of SO_2 in flue gas from both oil and coal-fired sources.

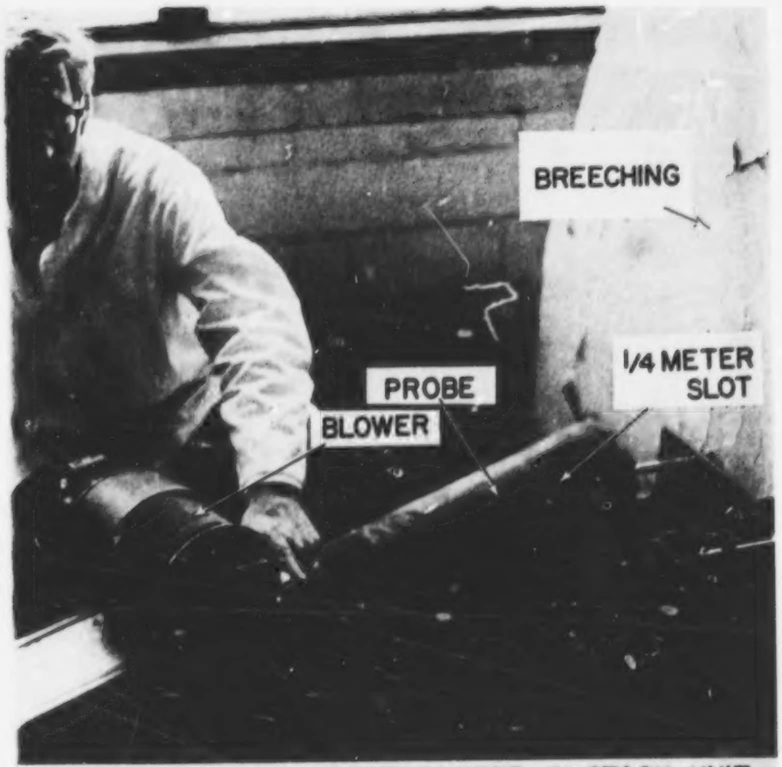
(2) The remote sensor is capable of making measurements of SO_2 in stack plumes over a wide range of sky brightness conditions provided that wind speeds do not exceed about 10 mph and the plume is well behaved. The error analyses tabulated in Tables 3.2 and A.8 clearly show that the errors become progressively worse as the slant range increases and also as the visibility decreases. It should be remembered that the error analyses shown in these Tables is based upon the sensor measurements equivalent to gas concentration at the stack exit and air dilution effects occuring within the flue have been omitted. This dilution does not effect the reference used for Table 3.2 and A.8, which was the in-stack shell measurement.

(3) Performance of the in-stack unit and remote sensor was not evaluated over a controlled range of flue gas aerosol content because it was not feasible to re-arrange the furnace combustion parameters of a production oriented facility.

3.7 ACKNOWLEDGEMENTS

It is difficult to express adequately, our appreciation to the following organizations for their very valuable assistance and co-operation provided to Barringer Research over the duration of the program. Without such generous assistance this program would not have been possible.

Gulf Oil of Canada Limited
The Hydro-Electric Power Commission of Ontario
Lever Brothers Limited


BREECHING
1/4 METER SLOT
PROBE
BLOWER

INSTALLATION OF SPECTROMETER IN-STACK UNIT
LEVER BROS. OCT. 69 FIGURE 3·1

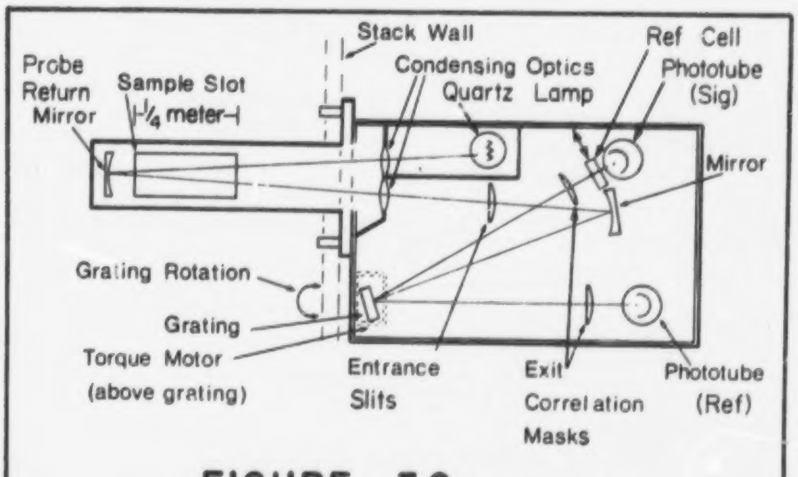
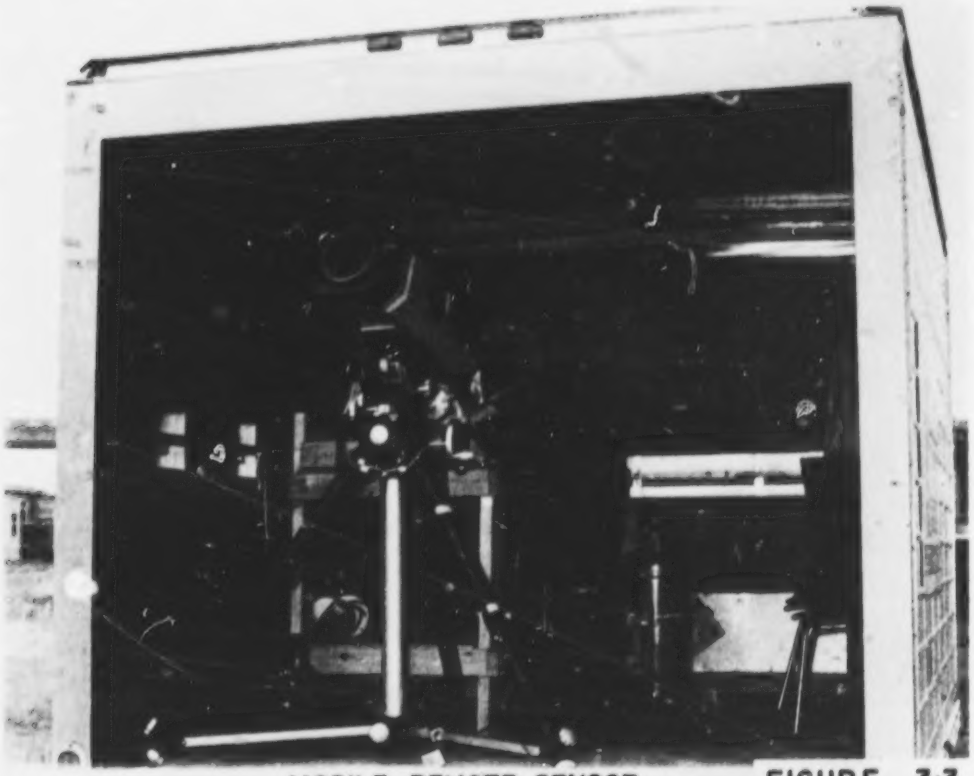

Stack Wall
Ref Cell
Probe Return Mirror
Sample Slot
|-1/4 meter-|
Condensing Optics
Quartz Lamp
Phototube (Sig)
Mirror
Grating Rotation
Grating
Torque Motor (above grating)
Entrance Slits
Exit Correlation Masks
Phototube (Ref)

FIGURE 3·2
SO_2 STACK MONITOR LAYOUT



MOBILE REMOTE SENSOR FIGURE 3·3

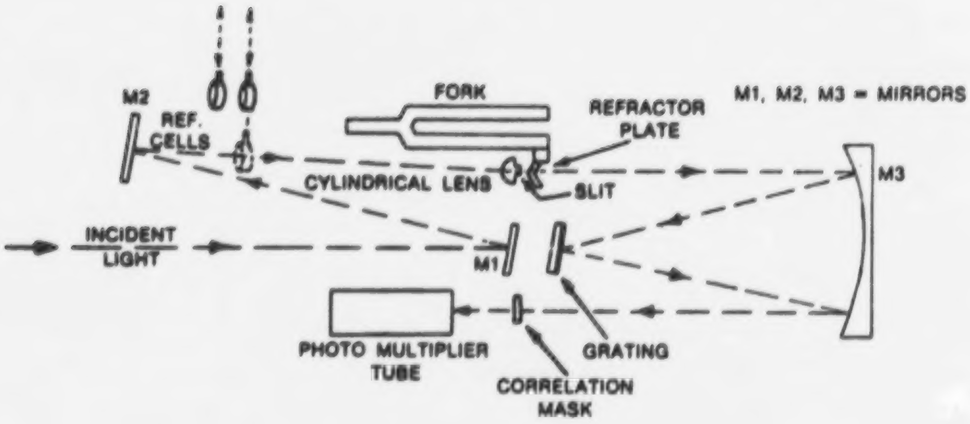
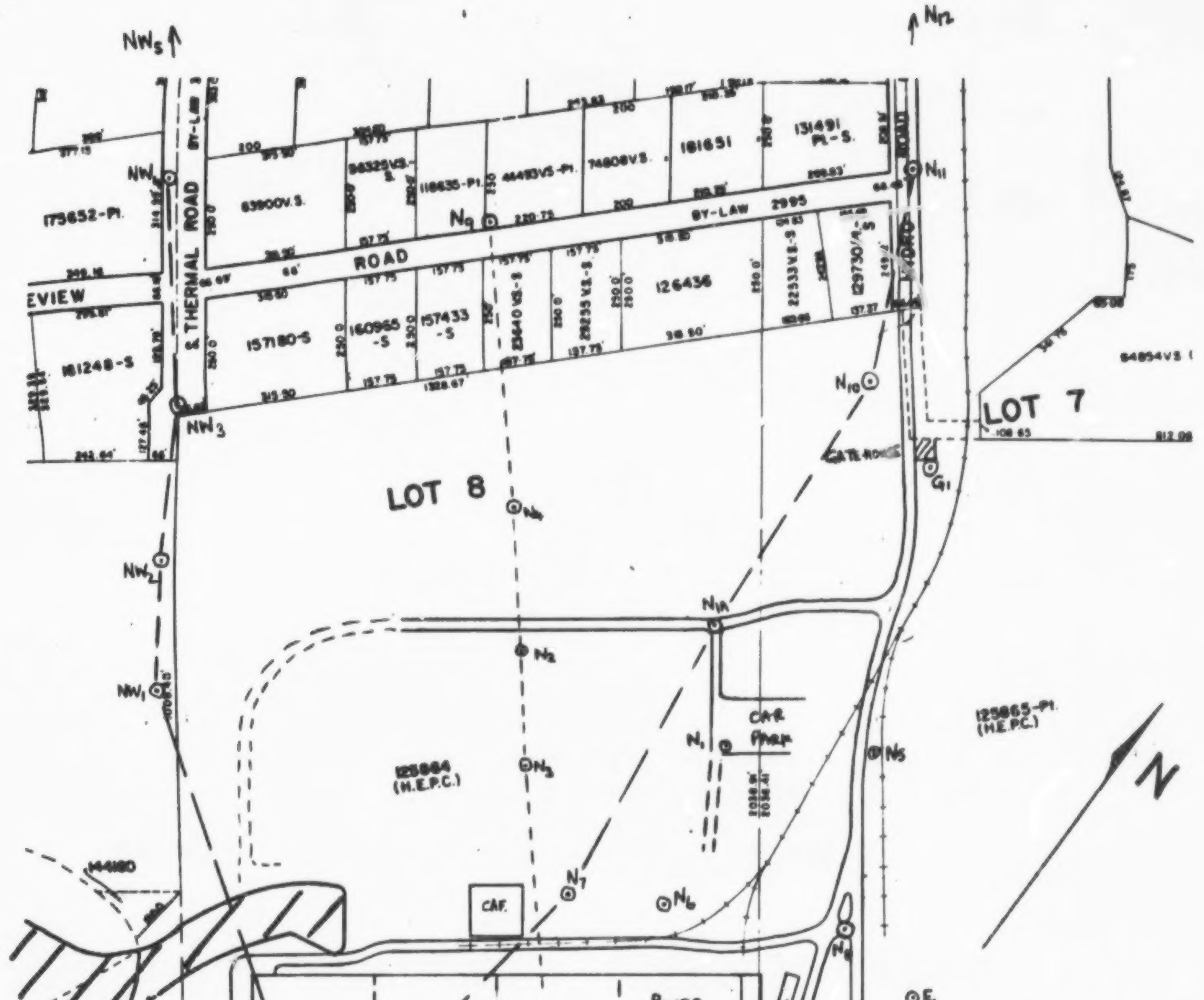

M2
REF. CELLS
FORK
REFRACTOR PLATE
M1, M2, M3 = MIRRORS
M3
CYLINDRICAL LENS
SLIT
INCIDENT LIGHT
M1
PHOTO MULTIPLIER TUBE
GRATING
CORRELATION MASK

FIGURE 3·4
Dispersive system for vapor detection using spectrum correlation filter.


NW5
N12
NW4
175652-PL
63900V.S.
N9
N11
BY-LAW 2995
ROAD
THERMAL ROAD
EVIEW
161248-S
157180-S
160965-S
157433-S
126436
181651
131491 PL-S
NW3
N10
LOT 7
84854VS
LOT 8
GATEHOUSE
G1
N14
NW2
N2
NW1
N1
CAR PARK
125864 (H.E.P.C.)
N3
N5
125865-PL (H.E.P.C.)
N
144180
N7
N6
CAF.
N8
E1
POWER HOUSE
7&8
5&6
3&4
1&2
STACKS #4
#3
#2
#1
CAR PARK
COAL DUMP
S6
S8
S9
W6
W5
W4
W3
W2
W1
S1
S2
S3
S10
S11
ACID PIT
SCALE FEET.
0
200
400
800
LAKE ONTARIO
COAL DOCK

LAKEVIEW GENERATING STATION FIGURE 3·5

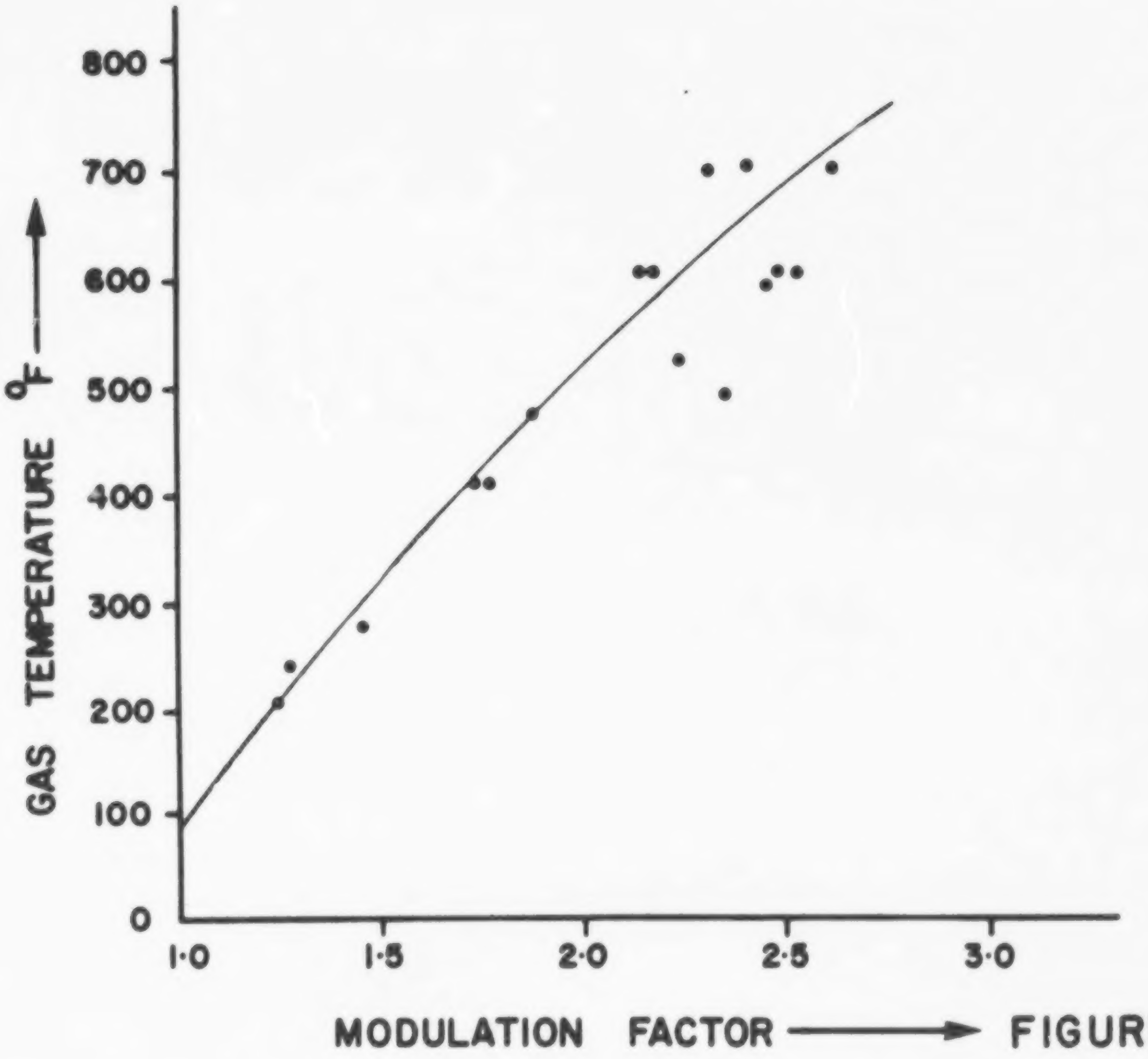
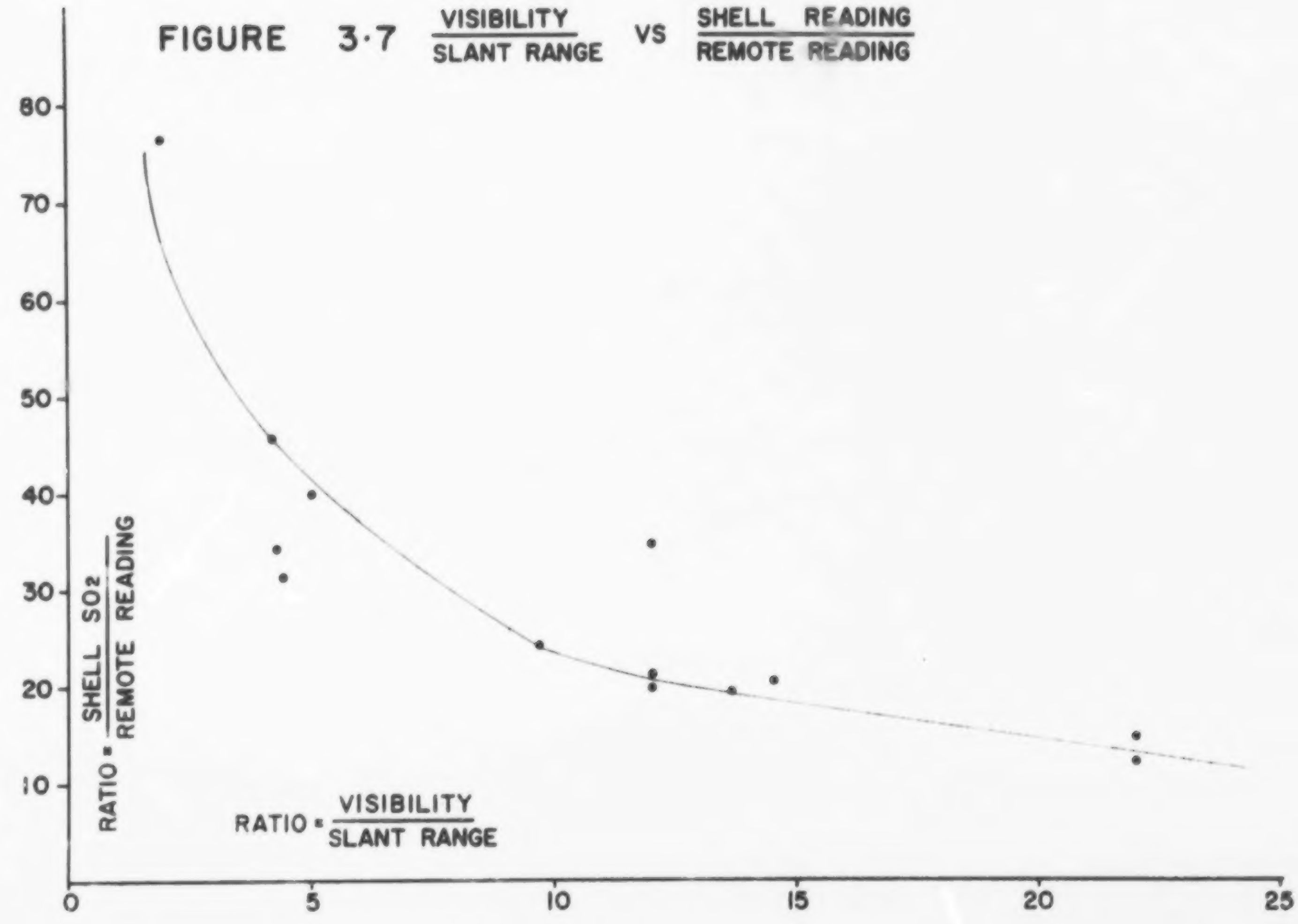


FIGURE 3·6

FIGURE 3·7 $\frac{\text{VISIBILITY}}{\text{SLANT RANGE}}$ VS $\frac{\text{SHELL READING}}{\text{REMOTE READING}}$



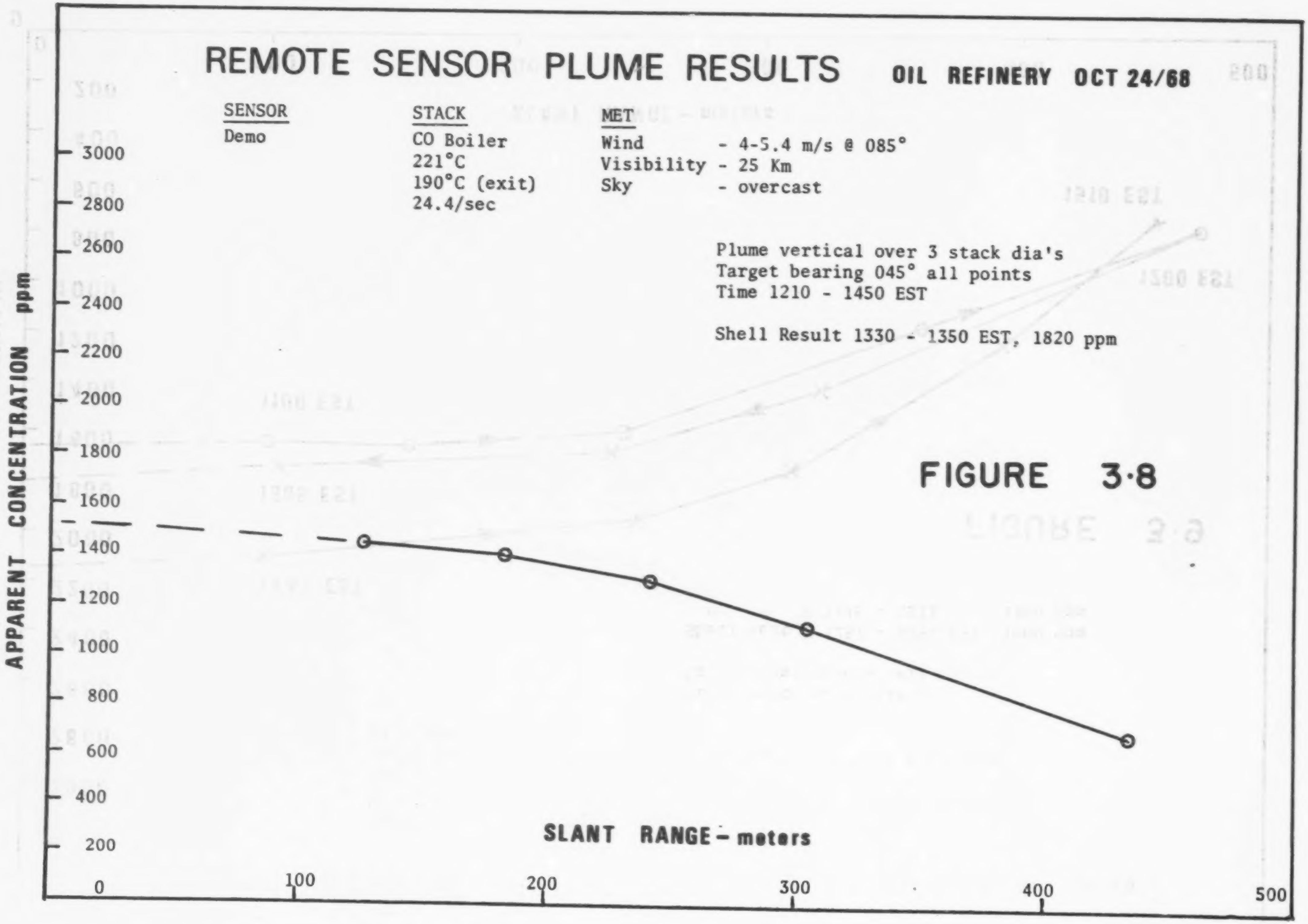
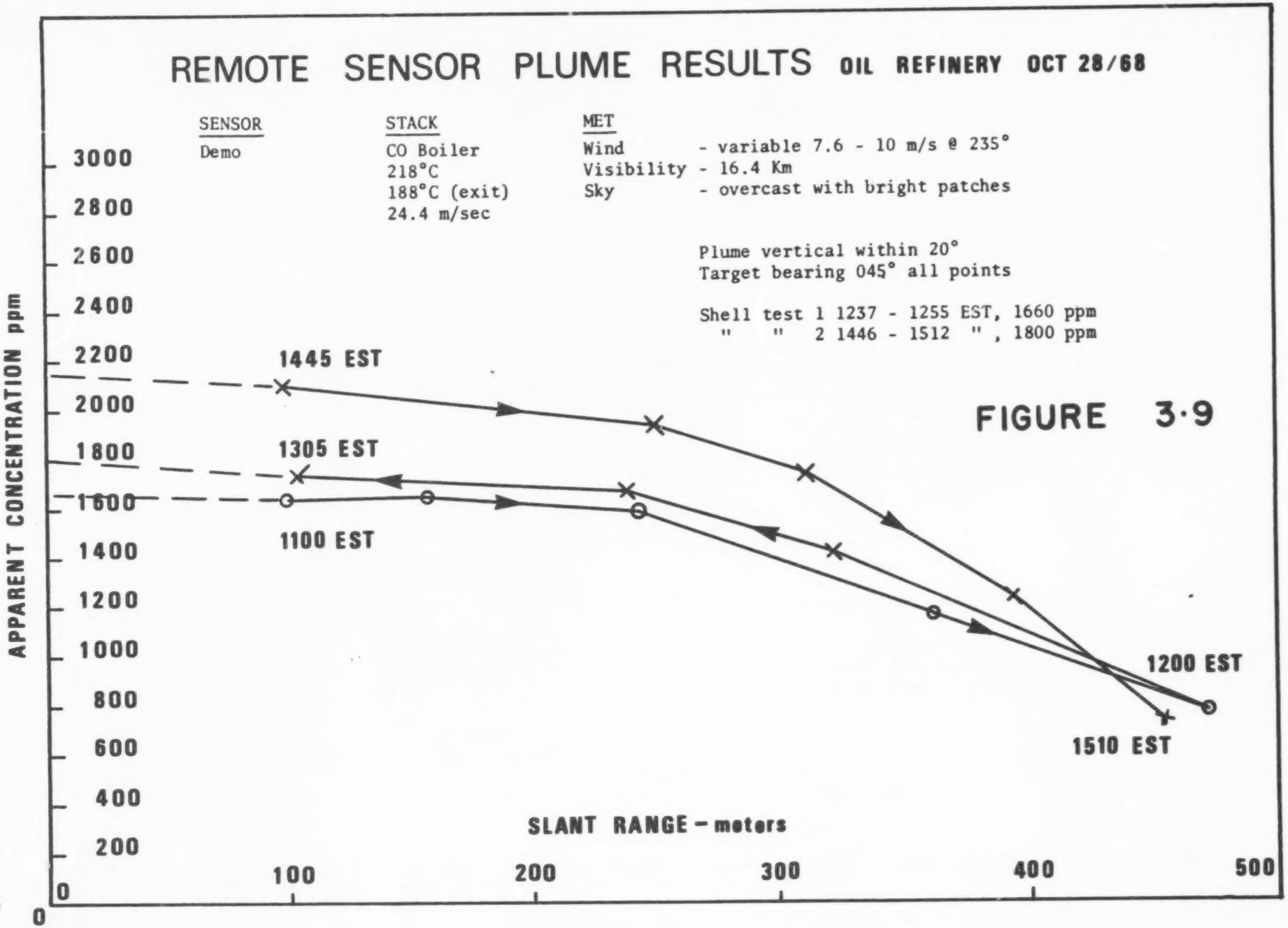

REMOTE SENSOR PLUME RESULTS
OIL REFINERY OCT 24/68
SENSOR
Demo
STACK
CO Boiler
221°C
190°C (exit)
24.4/sec
MET
Wind - 4-5.4 m/s @ 085°
Visibility - 25 Km
Sky - overcast
Plume vertical over 3 stack dia's
Target bearing 045° all points
Time 1210 - 1450 EST
Shell Result 1330 - 1350 EST, 1820 ppm
APPARENT CONCENTRATION ppm
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
100
200
300
400
500
SLANT RANGE – meters

FIGURE 3·8



REMOTE SENSOR PLUME RESULTS OIL REFINERY OCT 28/68

SENSOR	STACK	MET	
Demo	CO Boiler	Wind	- variable 7.6 - 10 m/s @ 235°
	218°C	Visibility	- 16.4 Km
	188°C (exit)	Sky	- overcast with bright patches
	24.4 m/sec		

Plume vertical within 20°
Target bearing 045° all points

Shell test 1 1237 - 1255 EST, 1660 ppm
" " 2 1446 - 1512 " , 1800 ppm

FIGURE 3·9

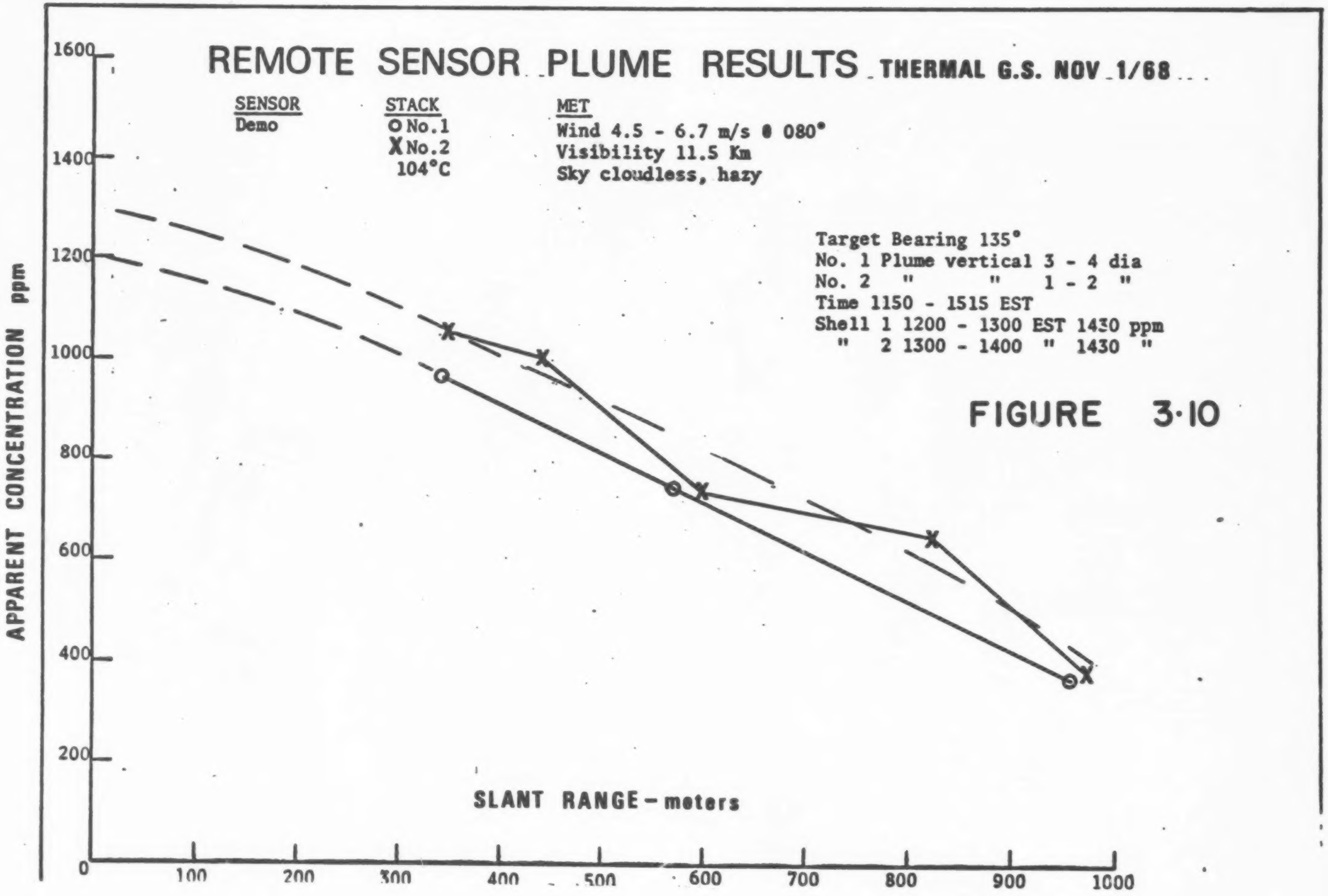
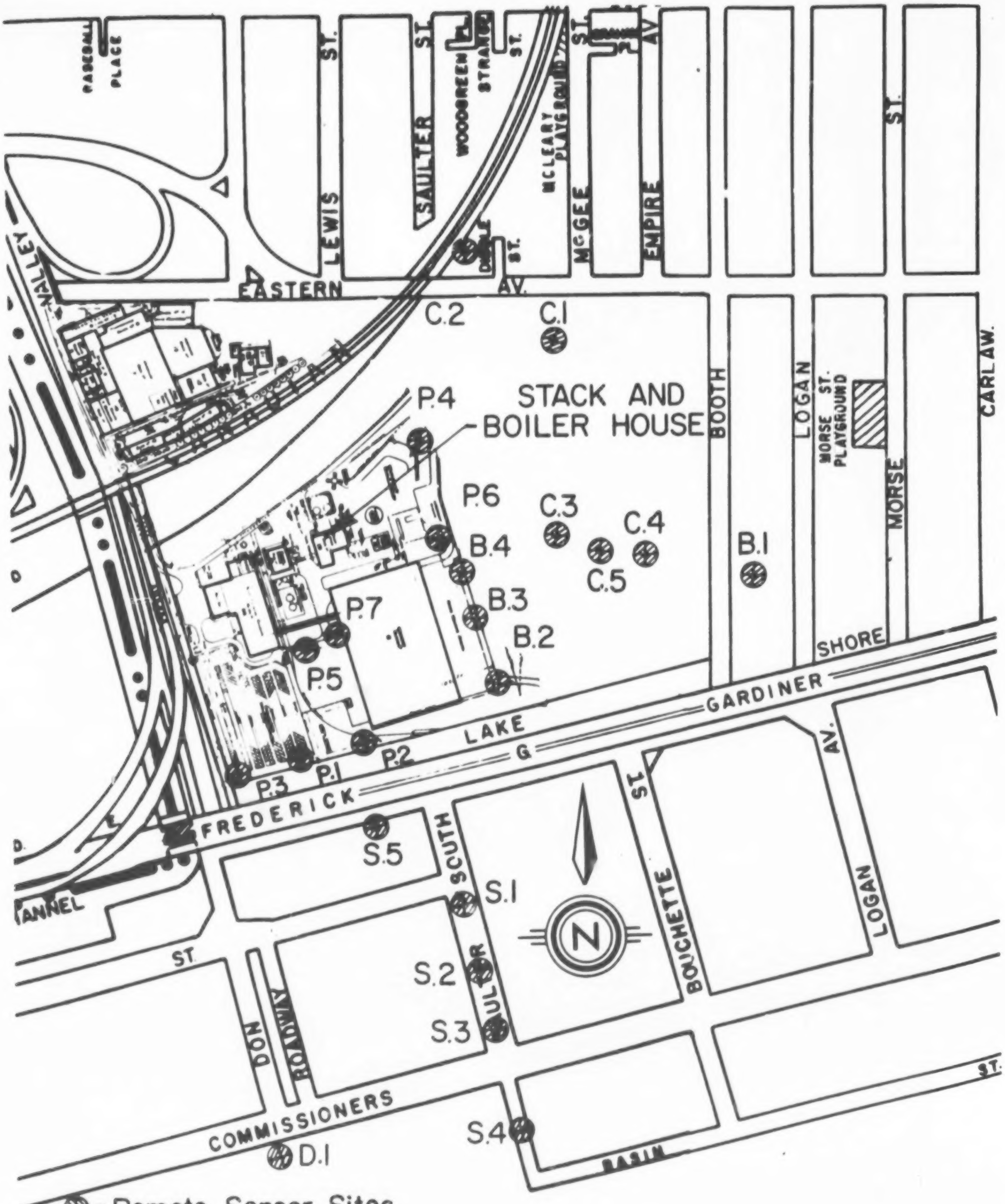


FIGURE 3·10

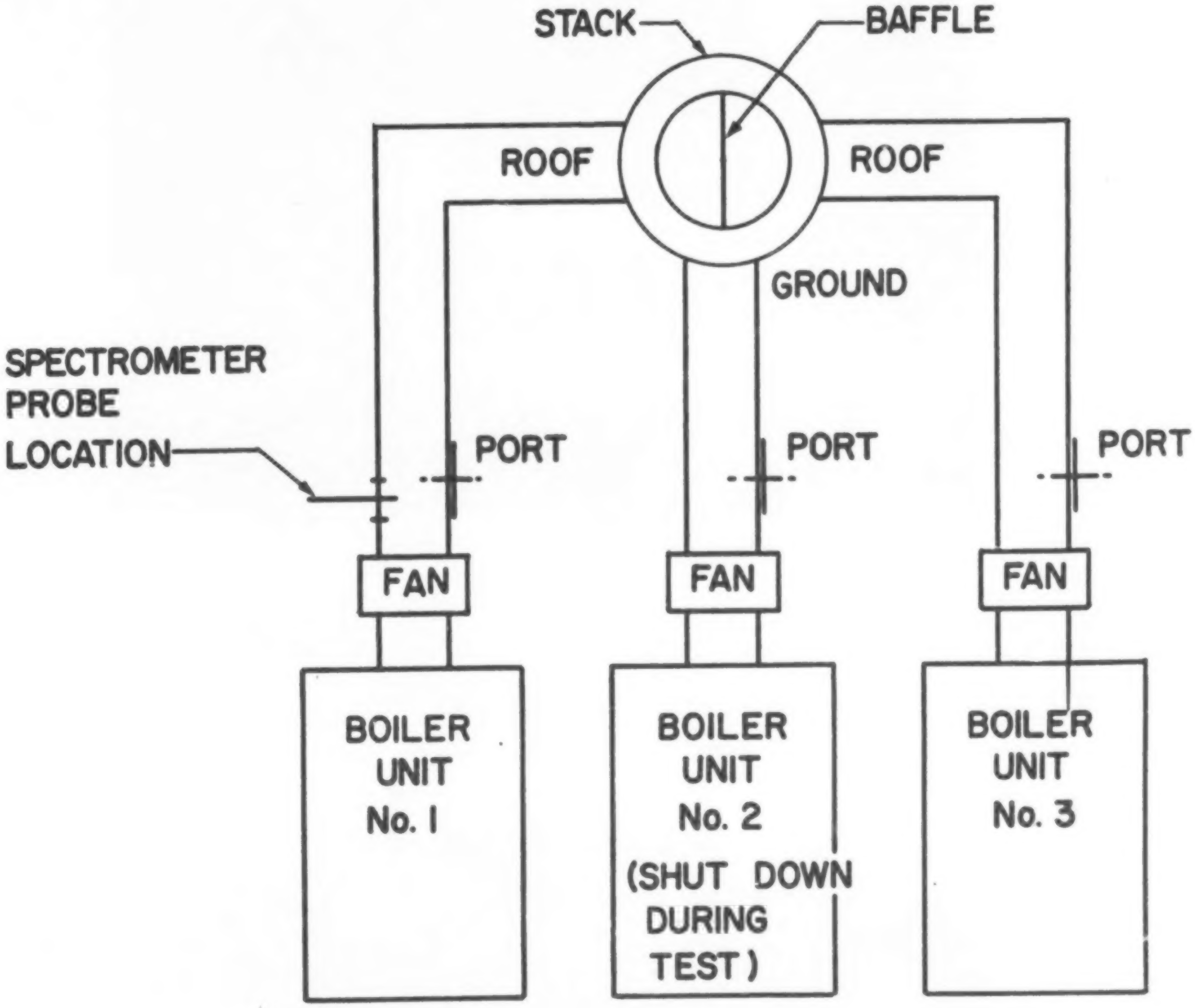
REMOTE SENSOR PLUME RESULTS THERMAL G.S. NOV 1/68
SENSOR
Demo
STACK
○ No.1
X No.2
104°C
MET
Wind 4.5 - 6.7 m/s @ 080°
Visibility 11.5 Km
Sky cloudless, hazy
Target Bearing 135°
No. 1 Plume vertical 3 - 4 dia
No. 2 " " 1 - 2 "
Time 1150 - 1515 EST
Shell 1 1200 - 1300 EST 1430 ppm
" 2 1300 - 1400 " 1430 "
APPARENT CONCENTRATION ppm
1600
1400
1200
1000
800
600
400
200
0
SLANT RANGE - meters
100
200
300
400
500
600
700
800
900
1000


VALLEY
LEWIS ST.
SAULTER ST.
WOODGREEN
STRAND
ST.
McLEARY PLAYGROUND
McGEE ST.
EMPIRE AV.
ST.
EASTERN AV.
C.2
C.1
P.4
STACK AND
BOILER HOUSE
BOOTH
LOGAN
MORSE ST. PLAYGROUND
MORSE
CARLAW.
P.6
C.3
C.4
B.4
C.5
B.1
P.7
B.3
B.2
P.5
SHORE
GARDINER
LAKE
G
P.3
P.1
P.2
FREDERICK
ST
AV.
S.5
SOUTH
S.1
N
BOUCHETTE
LOGAN
ANNEL
ST
S.2
S.3
DON
ROADWAY
COMMISSIONERS
ST.
S.4
D.1
BASIN

⊛ = Remote Sensor Sites

LEVER BROS. (OIL FIRED SOURCE)

FIGURE 3·11


STACK
BAFFLE
ROOF
ROOF
GROUND
SPECTROMETER PROBE LOCATION
PORT
PORT
PORT
FAN
FAN
FAN
BOILER UNIT No. 1
BOILER UNIT No. 2 (SHUT DOWN DURING TEST)
BOILER UNIT No. 3

LEVER BROS (OIL FIRED)
FIGURE 3·12

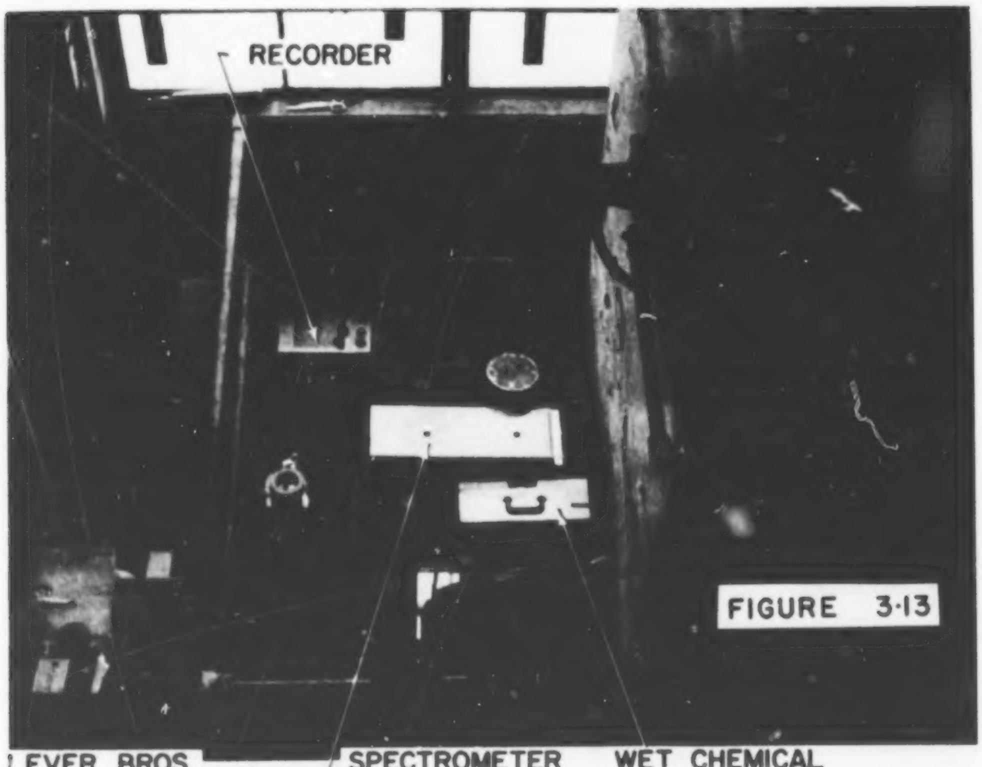

RECORDER
SPECTROMETER IN-STACK UNIT
WET CHEMICAL UNIT

FIGURE 3·13

LEVER BROS.
OCT. 69

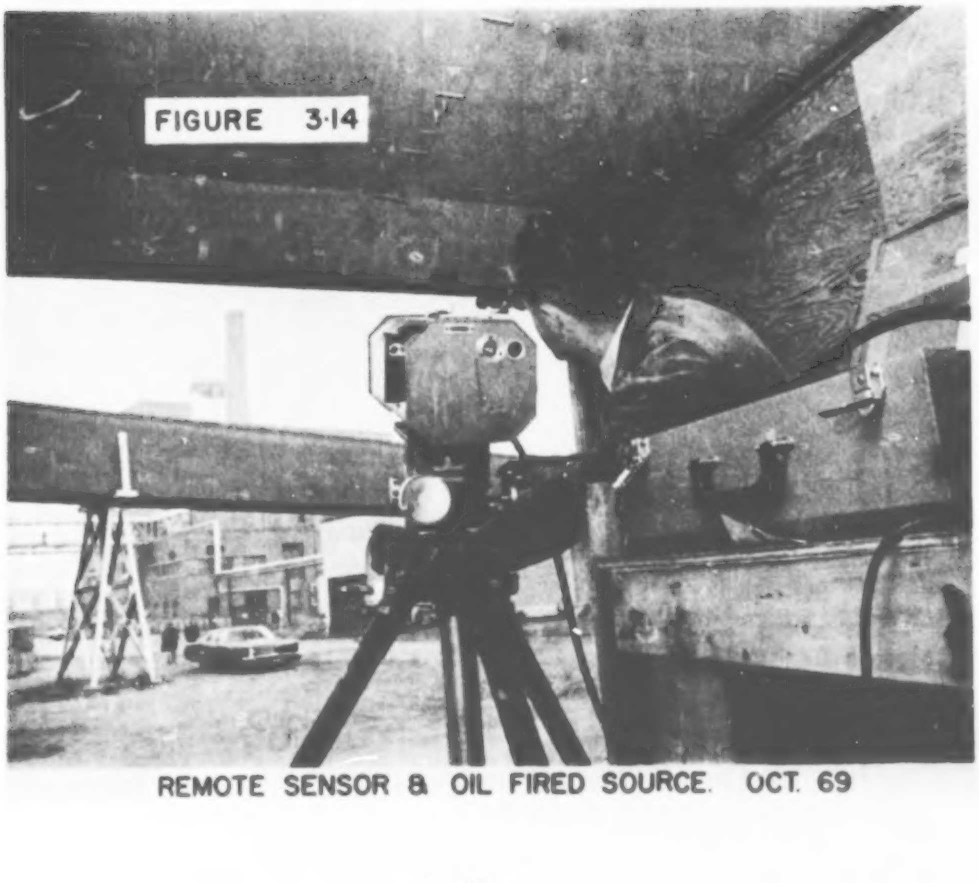
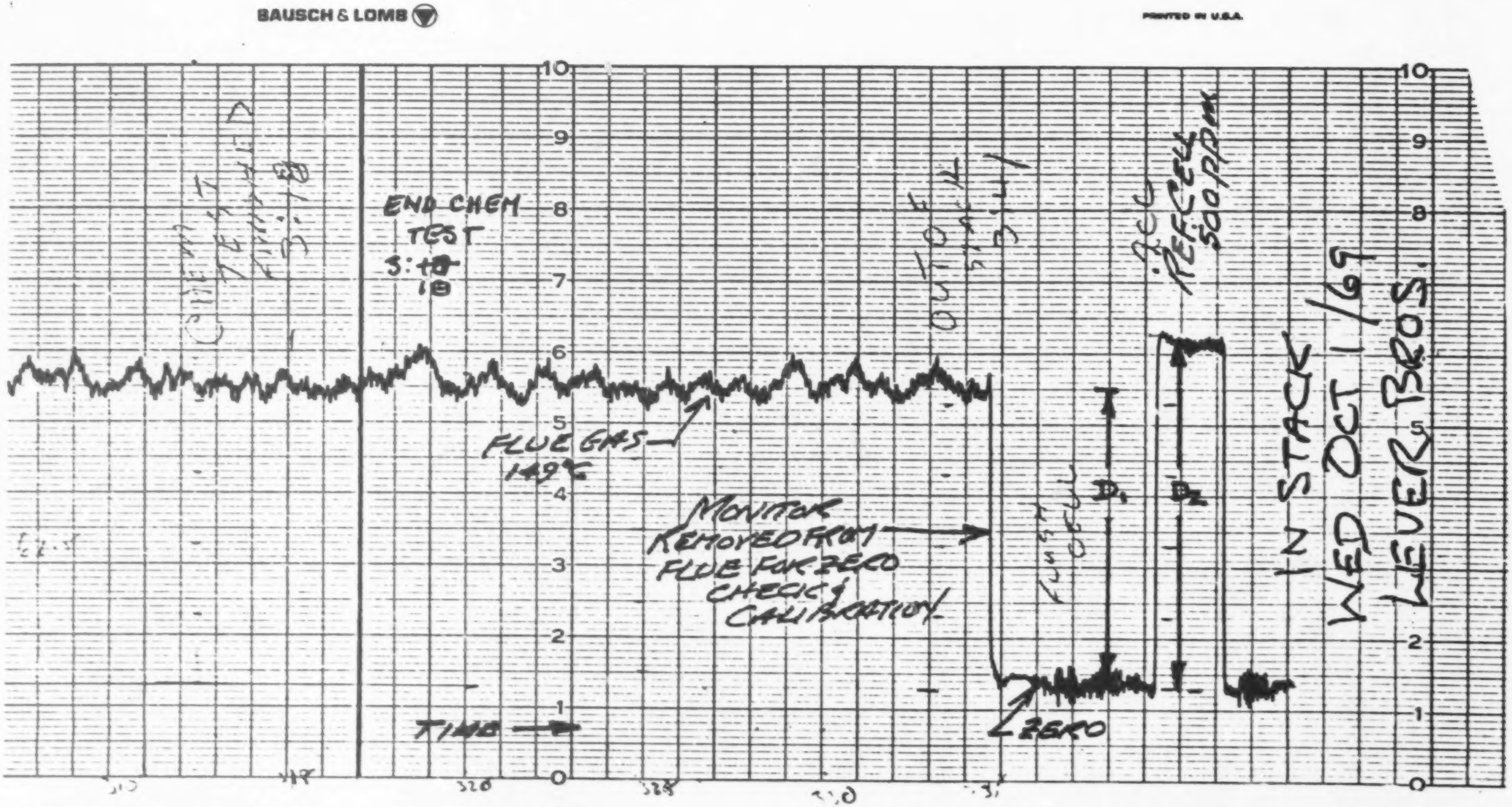


FIGURE 3·14

REMOTE SENSOR & OIL FIRED SOURCE. OCT. 69



LEVER BROS. OCT. 1/69 TYPICAL IN-STACK TRACE

FIGURE 3.15

]

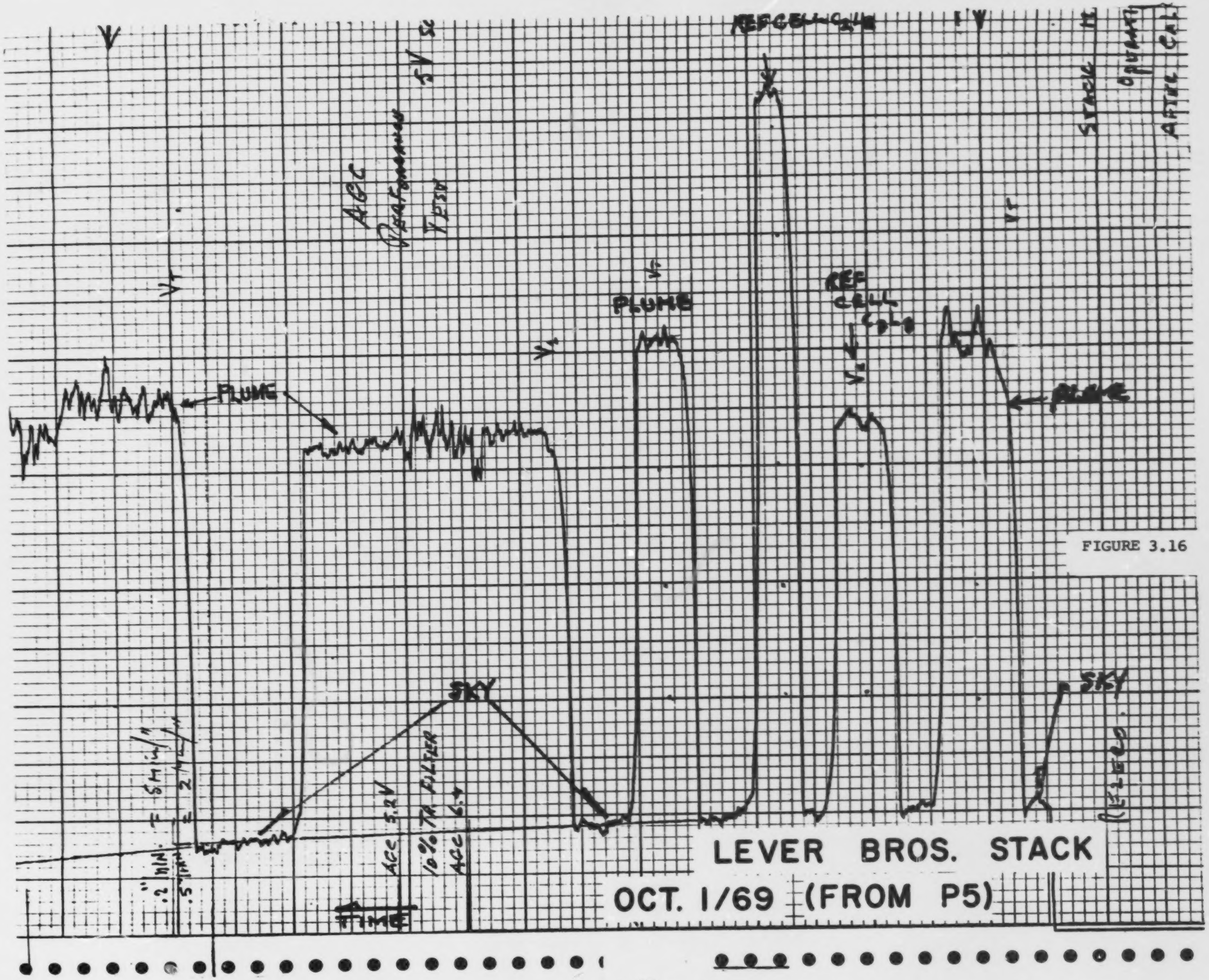


FIGURE 3.16

LEVER BROS. STACK
OCT. 1/69 (FROM P5)

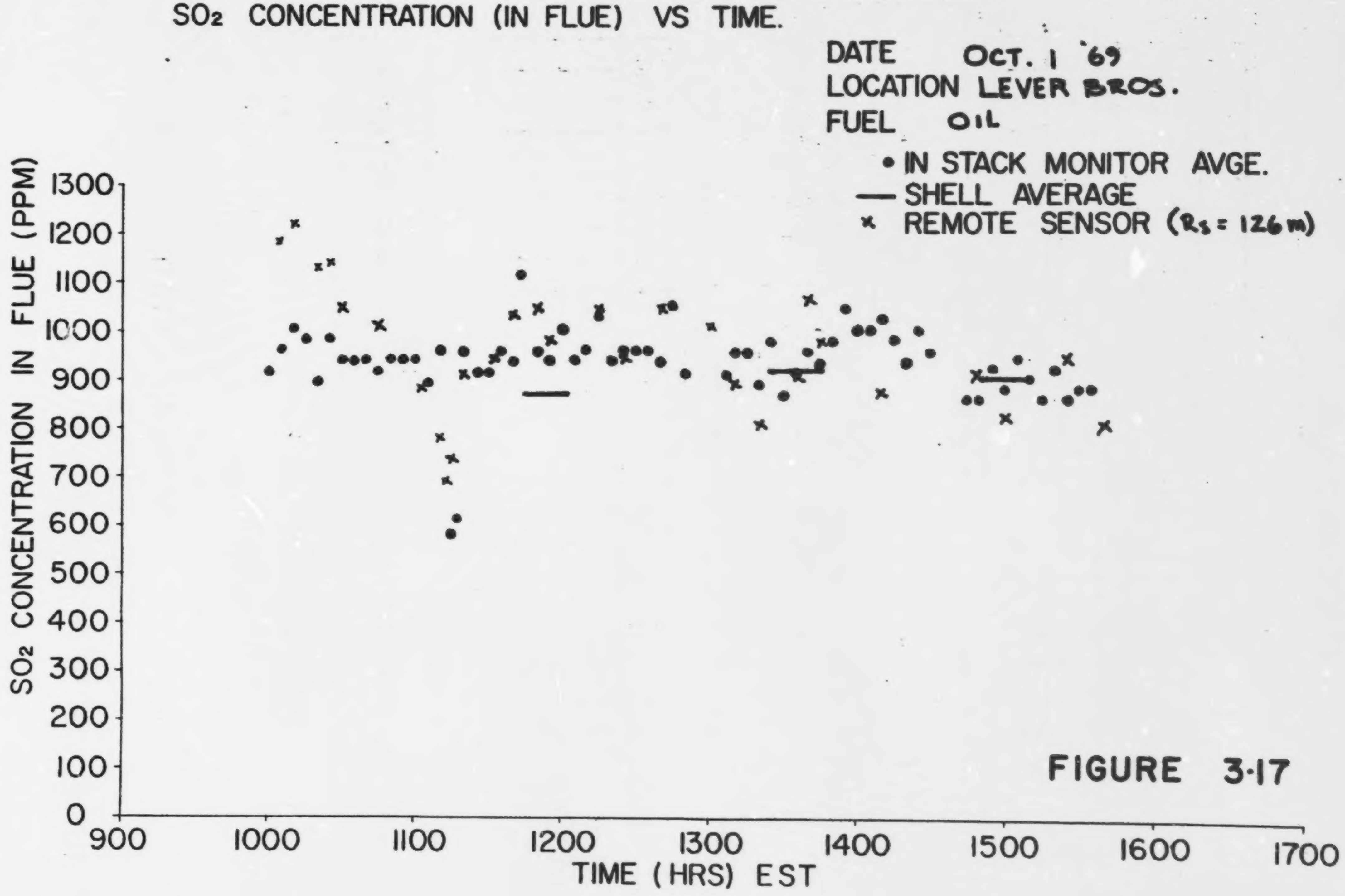
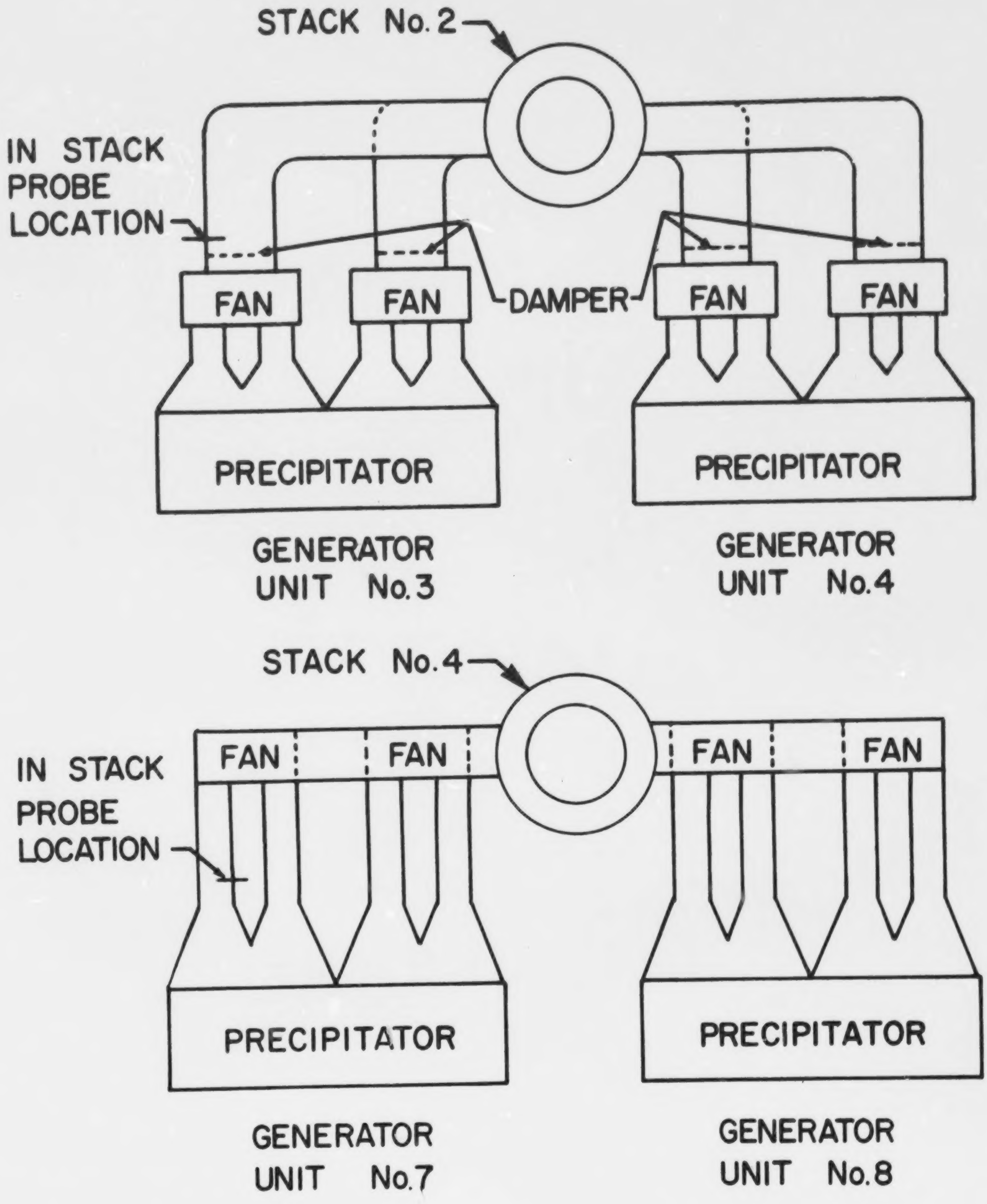

SO$_2$ CONCENTRATION (IN FLUE) VS TIME.

FIGURE 3·17


STACK No.2
IN STACK PROBE LOCATION
DAMPER
FAN
FAN
FAN
FAN
PRECIPITATOR
PRECIPITATOR
GENERATOR UNIT No.3
GENERATOR UNIT No.4
STACK No.4
IN STACK PROBE LOCATION
FAN
FAN
FAN
FAN
PRECIPITATOR
PRECIPITATOR
GENERATOR UNIT No.7
GENERATOR UNIT No.8

LAKEVIEW GENERATING STATION
(COAL FIRED)

FIGURE 3·18 (a)

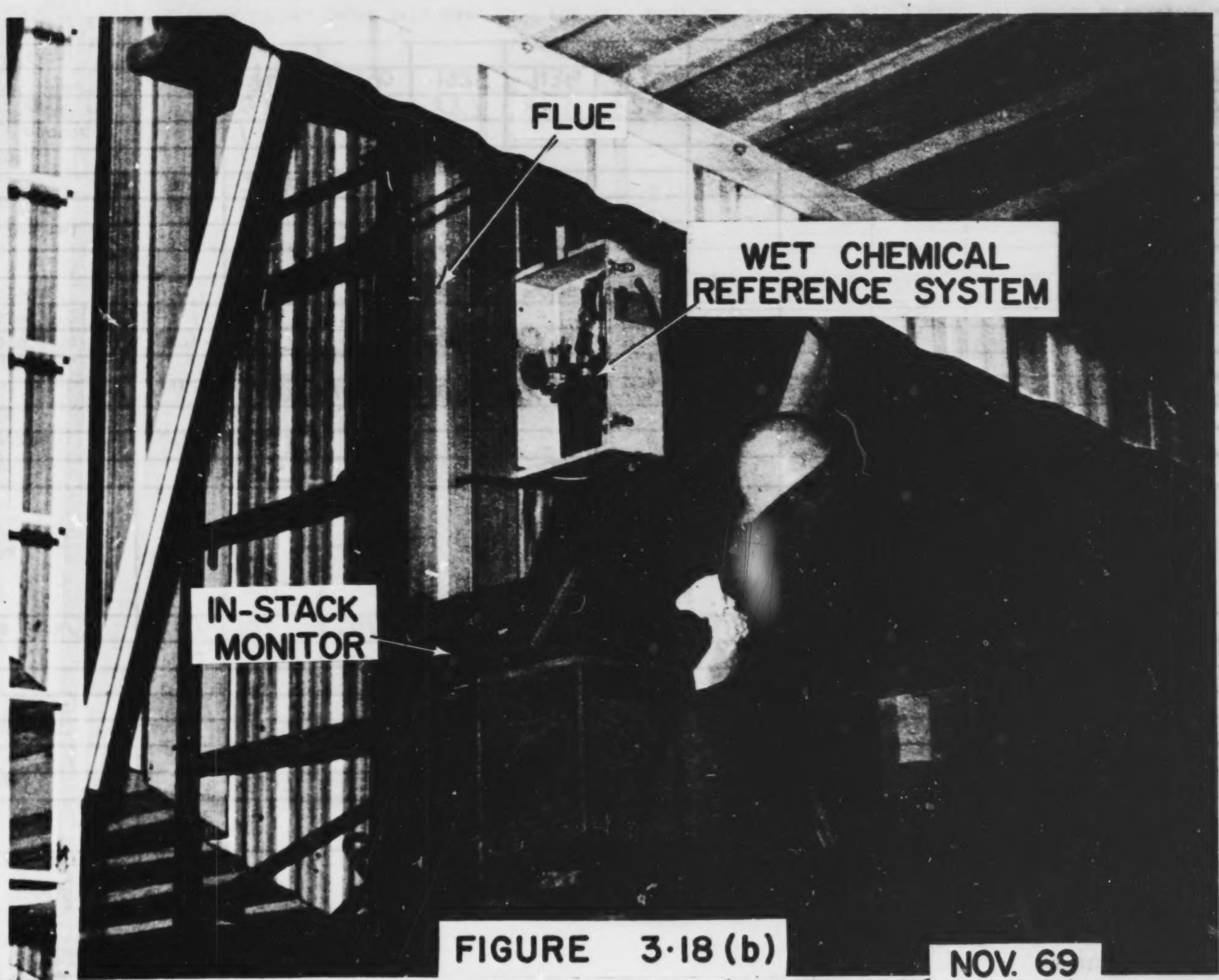

FLUE
WET CHEMICAL REFERENCE SYSTEM
IN-STACK MONITOR

FIGURE 3·18 (b)

NOV. 69

IN-STACK SPECTROMETER INSTALLATION LAKEVIEW G.S. UNIT No. 7

TABLE 3.3

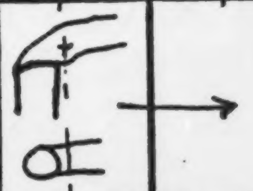
SO$_2$ REMOTE SENSOR DATA SHEET

STACK LOCATION. LEVER'S...

Sensor Ser. No. DEMO

REF. CELL C_1L_1 = 2900 C_2L_2 = 1350

DATE....OCT. 1 69......

		Note											
	No.		1	"	"	"	"	"	"	"	"	"	"
STACK	Ht (m)		42.7	"	"	"	"	"	"	"	"	"	"
	Dia (m)		2.6	"	"	"	"	"	"	"	"	"	"
	Temp. (°C)		150	"	"	"	"	"	"	"	"	"	"
METEOR	Sky	(1)	7	10	"	"	"	"	"	9			
	Vis.	(2)	15^{+}	"	"	"	"	"	"				
	Wind (mph/°)	(3)	10/	10/09	"	"	"	"	"	11/08			
	PLUME	(4)								SKY CLOUDING OVER	BLOWING TUBES		
SITE	No.		P5	"	"	"	"	"	"	"	"	"	"
	γ degree	(5)	19.8	"	"	"	"	"	"	"	"	"	"
SENSOR	Time	(6)	940	1004	1010	1020	1025	1027.5	1045	1102	1110	1112.5	1115
	Aperture		.5	"	"	"	"	"	"	"	"	"	"
	V_1 Div.	(7)	.65	62	62	"	"	"	"	62	"	"	"
	V_2 Div.		36	34	"	"	"	"	"	35	"	"	"
	V_T Div.		36	41	.42	39.5	39.5	37	36	33	29.5	27	28.5
RESULTS	AGC (volts)		5.	5.2									
	FOV. (m)		.21 .23	"	"	"	"	"	"	"	"	"	"
	XLT. (m)		2.76	"	"	"	"	"	"	"	"	"	"
	R_s (m)		126	"	"	"	"	"	"	"	"	"	"
	Temp. Factor		1.41	"	"	"	"	"	"	"	"	"	"
	SENSOR (ppm) AT STACK EXIT		687	861	887	823	823	760	736	640	559	504	537
	SENSOR (ppm) AT FLUE		947	1190	1225	1136	1136	1050	1015	883	771	695	740
	SHELL (ppm)												

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. .....

TABLE 3.3 (cont.)

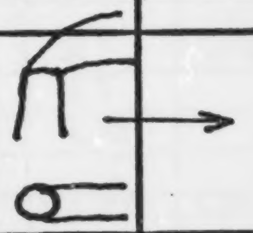
SO$_2$ REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = 2900 C_2L_2 = 1330

STACK LOCATION. LEVERS

DATE. 1 OCT 1969

Sensor Ser. No.

	No.	Note	1										
STACK	Ht (m)		42·7										
	Dia (m)		2·6										
	Temp. (°C)		300°F										
METEOR	Sky	(1)					5				7		
	Vis.	(2)	15+										
	Wind (mph/°)	(3)					15/08				14/07		
	PLUME	(4)											
SITE	No.		P5										
	& degree	(5)	19·8										
SENSOR	Time	(6)	1120	1132	1140	1150	1155	1215	1225	1240	1300	1310	1320
	Aperture		15										
	V_1 Div.	(7)	62	61	61			61			59		
	V_2 Div.		35	33·5	33·5	34		33·5			32		
	V_T Div.		34	33·5	36	37	35	36·5	33·5	35	34	30·5	28
RESULTS	AGC (volts)		5·0							4·95	4·9		
	FOV. (m)		·23										
	XLT. (m)		2·76										
	R_s (m)		126										
	Temp. Factor		1·41										
	SENSOR (ppm) AT STACK EXIT		663	687	749	762	712	761	687	761	738	650	589
	SENSOR (ppm) AT FLUE		915	948	1032	1050	981	1050	948	1050	1019	896	812
	SHELL (ppm)						875						

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ... ..

TABLE 3.3 *(cont.)*

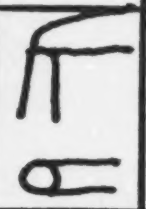
SO$_2$ REMOTE SENSOR DATA SHEET

Sensor Ser. No.

REF. CELL C_1L_1 2900 C_2L_2 = 1350

STACK LOCATION LEVERS.

DATE. 1st OCT 1969.

	No.	Note	1										
STACK	Ht (m)		42·7										
	Dia (m)		2·6										
	Temp. (°C)		300°F										
METEOR	Sky	(1)				5		4			5		
	Vis.	(2)	15+										
	Wind (mph/°)	(3)				17/07		17/07			17/08		
	PLUME	(4)		WIND STEADY SUNNY, LIGHT SCATTERED CLOUD									
SITE	No.		P5										
	& degree	(5)	19·8										
SENSOR	Time	(6)	1336	1340	1345	1410	1450	1500	1525	1540	1600	1615	
	Aperture		·5										
	V_1 Div.	(7)	59			59	57·5		58			55·5	
	V_2 Div.		32			31	31		31			30	
	V_T Div.		31	35·5	33	29	30	27·5	31	27	30	28	
RESULTS	AGC (volts)												
	FOV. (m)		0·21										
	XLT. (m)		2·76										
	R_s (m)		126										
	Temp. Factor		1·41										
	SENSOR (ppm) AT STACK EXIT		662	777	712	637	662	599	687	587	682	634	
	SENSOR (ppm) AT FLUE		915	1070	983	879	915	826	948	810	914	875	
	SHELL (ppm)				925			915					

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ......

Section 4

PHASE II

4.1 OBJECTIVES

The objectives of the Phase II tests were to monitor the emissions of nitrogen dioxide from sources using coal and oil fuels with high and low sulphur contents using the airborne sensor and to track the plume down wind to zero response of the instrument; analysis of the nitrogen oxides in the stack by wet chemical means to be included for reference. Thus from these measurements it would appear possible to check upon the conversion of NO to NO_2.

In most boiler plants and in a a number of furnaces, excess oxygen is kept to a minimum for reasons of economy. This results in sulphur being emitted as SO_2 rather than as SO_3 and nitrogen as NO rather than as NO_2. The NO is oxidized in the atmosphere to NO_2 which can then initiate photochemical reactions and promote the development of smog. There are several ways in which NO can be oxidized, but the method and the rate of oxidation are unknown and measurement is difficult during the natural diffusion and dilution of a plume. The Barringer airborne remote sensing NO_2 spectrometer provided an instrument technique whereby the concentration-pathlength of NO_2 below the aircraft could be followed as the aircraft overflew the plumes.

4.2 THEORETICAL BACKGROUND

If a remote correlation spectrometer is set looking vertically upwards, then ignoring the light scatter into the instrument by particulate matter in the light path, the light falling on the phototube originates from a small part of the sky defined by the instruments field of view and the signal generated by the instrument will be a function of the amount of target gas within the field of view. In the case of an aircraft flying above the inversion layer or above most of the atmospheric pollution, this upward looking signal is very small and the instrument can be zeroed under these conditions. If the airborne spectrometer is now put in the downward looking mode, the increase in signal will be a function of the additional target gas in the extended light path. As a first approximation this additional light path is twice the height of the aircraft. However, since the terrain beneath the aircraft within the field of view of the instrument gives diffuse and not specular reflection the light reflected to the spectrometer from the ground target contains components from the 2π dome of the sky. It can be shown that for a gas cloud in the form of an infinite layer between the aircraft and the ground, the effective optical pathlength through the gas layer is greater than twice the height of the aircraft since the direction of maximum illumination of the ground is at an oblique angle through the gas layer. The effect of this oblique traverse can be obtained from a computer program which is used to handle the airborne data.

4.3 INSTRUMENTATION

The airborne sensor used was a Barringer NO_2 remote sensor optimized for high sensitivity to nitrogen dioxide and a fast response time of about one second. The NO_2 spectrometer was installed in an Aerocommander aircraft as shown in Figure 4.1; it has been successfully used in the past and is described in detail in reference 1.

Briefly, the airborne system consists of the remote sensor looking into a 45° mirror which can be rotated to reflect light from either the ground below the aircraft or the sky above. The mirror is housed in a pod on the side of the aircraft and is clearly visible in Figure 4.2 which shows a low level flight along the Toronto waterfront. Data is collected on a multi-channel oscillograph recorder which records, in addition to the remote sensor output, the AGC voltage which is a measure of the total light flux. It also records the barometric pressure and an event marker records the frames of the flight path recovery camera.

In operation, the aircraft flies above the inversion layer which is normally clearly visible from the aircraft and could also be checked by air temperature measurements. The assumption is then made that the amount of gas above the aircraft is negligible, thus a zero can be established by setting the mirror to reflect skylight from above into the aircraft and adjusting the zero accordingly. The zero is normally checked at each end of a flight line and the sensitivity is checked by inserting a calibration cell of known gas concentration and path-length product into the optical path.

The simultaneous analyses of oxides of nitrogen in the stacks under surveillance was performed by wet chemical methods. The total oxides of nitrogen were determined by exposing a known volume of gas to a sodium hydroxide solution. Absorption of the nitrogen dioxide by the sodium hydroxide upsets the equilibrium and causes the oxidation of more nitric oxide. After a period of about an hour, the oxidation is complete and the total nitrogen dioxide is determined by the addition of phenol disulfonic acid and subsequent colorimetric analysis at 4100 Å. The colorimetric response is calibrated from standard solutions of sodium nitrite.

4.4 EXPERIMENTAL SETUP

Arrangements were made to follow plumes from both the Lakeview Generating Station and the Gulf Refinery. Both these sources are located on the north shore of Lake Ontario and to eliminate the noise associated with changes in ground albedo when flying over land, all flights were made over the Lake.

Neither one of the two pollution sources selected is ideal since both are comprised of multiple stack sources. The Lakeview Generating Station had five boilers on line exhausting through three stacks, only one of which has sampling facilities. The three plumes however, quickly merge and the airborne survey consequently covers the combined plumes. Since this is a base load station with all units evenly loaded and burning the same fuel, the error in taking one stack as representative can be expected to be quite small. At the time of the tests, the total coal feed was 500T/hr. with 3% excess oxygen. A typical measured nitrogen oxide content of 190 ppm is equivalent to a nitrogen dioxide release of 14.9 M^3/min., as shown later in Section 4.6.

At the Gulf Refinery, there are three boilers and an assortment of process heaters and tube stills. These plumes quickly coalesce and no meaningful estimate of the total production of nitrogen oxides can be made. The airborne data however, would indicate the rate of conversion of NO to NO_2.

The aircrew attempted to fly a sinuous path over the plume. However, due to the micrometerological effects of the large body of cold water of Lake Ontario, pronounced curvature of the plume was found and it was found advantageous to locate the downwind end of the plume and develop the flight path from that point back towards the point where the plume could be located by direct vision. In this case, the gas at the downwind end of the plume had been emitted from the stack some 90 minutes before measurement. Arrangements were therefore made to sample the stack for a period of at least 90 minutes before the flight started and to continue until the aircraft arrived at the stack.

The success for these series of measurements depended on the selection of satisfactory meterological conditions. In many cases tests were started under satisfactory conditions but subsequently had to be aborted due to the buildup of cloud or a change in wind direction, these conditions being particularly difficult to predict because of the total elapsed time of the airborne survey.

Some difficulty was encountered in deciding how far the plume could be followed. Under flight conditions the recognition of small changes in the signal when the plume is widely dispersed is a matter of some difficulty and in many cases the processing of the data in the laboratory showed satisfactory indications of the plume when these indications were not apparent in the aircraft. This caused many flights to be discontined based upon the airborne operator's judgement, while subsequent data analyses at the laboratory indicated that further flight continuations could have obtained useful measurements.

The decision to carry out the airborne plume survey over Lake Ontario to take advantage of the steady reflective background of the Lake surface, necessitated a steady north or northwest wind and in general flights were only attempted during these conditions.

Three flights have been selected for detailed examination and they were flown on August 27 (flight I), September 30 (Flight II) and October 31, 1968 (flight III). During Flight I, the wind was northwesterly but during Flights II and III, wind shear was encountered. During Flight **II**, the plume started initially from the northwest, but rose to come under the influence of a southwesterly wind, while during Flight III the plume started inland under the influence of a southerly on-shore breeze and reversed direction under the influence of a north wind at higher altitudes.

4.5 RESULTS

4.5.1 Results - Flight I Lakeview Power Station - August 27, 1968

August 27th was a clear cool day with a 70° temperature, with north and northwest winds at 12 miles per hour. Eight parallel flight lines were laid down at 1-1/2 mile intervals downwind from the Lakeview Generation Station. The complete survey consisted of traversing the plume along each of eight flight lines in the outward direction from the stack with a flight on every other flight line on the return back to the start a total of eleven passes. The location of the flight lines in relation to the coast and Lake Ontario are shown in Figure 4.3. From the correlation spectrometer chart the plume width, height, and area under the curve have been computed for each traverse of the plume along the various flight lines.

Table 4.1 gives the data derived from the eleven passes. Columns 2, 4 and 6 show the trace dimensions in centimeters taken from original record while columns 3, 5 and 7 give the quantities derived from the calibration constants. Figure 4.4 shows a plot of the NO_2 burden (col. 7 of Table 4.1) plotted against distance. The plot indicates that there is a general increase in NO_2 burden with distance, but there is no evidence that the reaction is approaching completion. Figure 4.5 shows the relative plume shapes and indicates that the plume width and concentration apparently do not change in a regular manner. Visual observation of

TABLE 4.1

DATA FOR PLUME MEASUREMENT

LAKEVIEW G. S. - AUG. 27, 1968

1	2	3	4	5	6	7 *	8
Pass No.	Trace Length Cms.	Plume Width M	Peak Ht. Cms.	NO_2 ppm-m	Planimeter Area Cm^2	NO_2 ppm-m^2 x1000	Distance Miles
1	1.1	315	4.0	31.1	2.4	2.4	0.5
2	3.0	860	3.4	26.4	5.0	5.0	2
3	8.1	2320	3.1	24.1	10.8	11	3.5
4	5.7	1640	5.1	39.6	14.0	14.3	5
5	8.4	2410	4.7	36.5	27.0	27.3	6.5
6	9.5	2720	4.6	35.7	30.5	30.8	8
7	11.6	3330	5.1	39.6	34.4	34.7	9.5
8	9.2	2640	6.0	46.6	34.2	34.5	11
9	8.7	2570	3.5	27.2	21.0	22.0	8
10	4.8	1390	2.5	19.4	6.2	6.3	5
11	4.8	1390	3.1	24.1	6.3	6.4	2

Wind Velocity = 15 mph. 12 mph.
= 27 m/sec 5.4 m/sec

* Divided by 2.2 for the 'm' factor

TABLE 4.2

ADJUSTED DATA FOR AUG. 27 PLUME

1 Pass No	2 ADJ Plume Width M	3 ADJ Peak NO_2 ppm-M	4 =2 x 3 $x10^3$	5 * Corrected NO_2 Burden ppm-M^2 x1000	6 NO_2 Flow M^3/min
1	320	31	10	2.4	0.8
2	850	26	22	4.9	1.6
3	1300	23	30	5.9	1.9
4	1750	25	44	9.7	1.9
5	2200	30	66	20.5	6.6
6	2650	35	93	29.5	9.3
7	3100	39	121	31.5	10.0
8	3550	46	163	46.1	14.5
9	2650	35	93	29.5	9.3
10	1750	25	43	10.0	5.2
11	85	26	22	4.4	1.4

* Divided by the 'm' factor

plumes indicates that under the influence of the wind, a plume may undergo looping or fanning and that these effects may stretch or break the plume so that on a given traverse, an airborne sensor of the type in use for these tests might record a double thickness through a loop or a double width due to fanning or might record almost no plume. In an attempt to overcome these effects the plume width and NO_2 burdens are plotted against distance in Figure 4.6 and smooth curves drawn through the points. The plume width shows a fairly regular increase with distance, reaching 3500 meters at a distance of 16,000 meters to give a plume half angle of approximately 6.5° in good agreement with theory. (see Ref. 6)

The values for the NO_2 burden are variable but show a well defined minimum at a distance of about 3-1/2 miles from the stack. At a point about 4 miles from the stack, the burden of NO_2 begins to increase in an apparent linear manner with distance in spite of the increasing width of the plume. Table 4.2 shows a recalculation of the total NO_2 burden based on the smoothed curves of Figure 4.6 and the total NO_2 flow calculated from the corrected NO_2 burden in column 5 and a wind velocity of 12 m.p.h. The effect of smoothing the width and NO_2 burden are shown by the reduced scatter of the points in Figure 4.7 compared to Figure 4.6 This graph appears not to go through the origin but to show an initial NO_2 rate of 0.5 m^3/ min. It also indicates that the rate is not linear with time but increases for a period of at least 30 minutes after leaving the stack.

Calculation for smoothing plume width and vertical burden:
From Table 4.1.

Plume width = 1640 metres
Vertical Burden = 39.6 ppm-m
Product = 65,000 ppm-m^2
Planimeters = 14,300 ppm-m^2
Factor = $\frac{14,300}{65,000} = .22$

Smoothed Plume Width (Table 4.2) = 1750 metres
Smoothed Vertical Burden = 25 ppm-m
Product = 44,000 ppm-m^2
Smoothed Planimeter = 44,000 x .22
= 9,700 ppm-m^2
= Corrected Burden

4.5.2 Results - Flight II Lakeview Generating Station - September 30, 1968.

This flight indicates the usefulness of the airborne spectrometer system in chasing plumes after they cease to be visible in the naked eye. By observation the plume was blown out over the lake under the influence of a northwest wind, estimated to be about 4 miles per hour. However, about 4 miles over the lake the plume passed through a wind shear and then proceeded under the influence of a southwest wind at about 20 miles per hour. The nitrogen dioxide signal from this plume was traced for a distance of 25 miles where the width of the plume had increased to approximately 8000 meters. Traverses were then made at 4 mile intervals back to the stack. The locations of the traverses in relation to the coast of Lake Ontario are shown in Figure 4.8.

TABLE 4.3

LAKEVIEW G.S. - SEPTEMBER 30, 1968

	Trace Length Cms	Path Length M	Peak Height Cms	NO_2 ppm-M	Planimeter Area Cm^2	NO_2^* ppm-M^2 x1000	Dist. Miles
1.	5.2	1520	0.7	9.2	1.7	2.9	2
2.	7.9	2320	0.8	10.5	3.2	5.5	5
4.	24.9	7320	0.6	8.5	9.3	16.0	25
5.	25.4	7470	0.7	9.2	8.2	13.8	25
6.	26.7	7850	0.9	11.8	14.7	25.1	22
7.	22.8	6700	1.5	19.7	17.8	31.2	18
8.	19.7	5790	0.9	11.8	12.2	21.0	14
9.	14.7	4310	2.2	15.8	18.6	32.0	10
10.	12.8	3770	2.6	34.2	21.0	36.2	6
11.	10.2	2990	2.3	30.5	14.6	25.1	4
12.	7.6	2230	1.0	13.2	4.6	8.0	3

* Divided by 2.2 for the 'm' factor

TABLE 4.4

SEPTEMBER 30, 1969

LAKEVIEW POWER STATION

1 Pass No	2 ADJ Plume Width M	3 ADJ Peak NO_2 ppm-M	4 =2x3 $x10^3$	5* Corrected NO_2 ppm-M^2	6 NO_2 Flow
1	1500	12	13.5	2.9	.8
2	2700	30	83	19.5	10.5
4	7600	9	73	20.15	11.0
5	7600	9	73	20.5	11.0
6	7000	11	91	19.5	10.5
7	6300	16	134	31.8	17.2
8	5300	21	132	41.5	22.3
9	4400	29	127	37	20.0
10	3200	34	102	29	15.5
11	2300	26	50.6	14.5	3.9
12	1900	20	30	8.2	2.0

* Divided by 2.2 for the 'm' factor

As in the previous flight, the data read from the recorder chart is shown in Table 4.3 and the integrated NO_2 times width burden is plotted against distance in Figure 4.9. The plume width and vertical burden are plotted in Figure 4.10, which is used as a basis for the adjusted widths and burdens used in Table 4.4. In this graph, the influence of the low wind speed on the vertical NO_2 burden is clearly shown. The low wind speed influences the NO_2 concentration by suppressing turbulent mixing and by its failure to "stretch" the plume. Thus, the minimum which was a feature in the previous flight in either missing or becomes of minor importance and the vertical burden builds up to a very high value before the faster upper winds promote diffusion. The corrected NO_2 flow is plotted against distance and time in Figure 4.11, which indicates a maximum flow rate of 22.3 M^3/min.

$$\begin{aligned} 22.3\ M^3/\text{min.} &= 22.3 \times 60\ \ M^3/\text{hr.} \\ &= 22.3 \times 60 \times \frac{46}{22.4}\ \ \text{kg/hr.} \\ &= 2.73\ \text{te/hr.} \\ &= 3.0\ \text{tons/hr.} \end{aligned}$$

4.5.3 Results: Flight III Gulf Refinery - October 31, 1968.

This flight was carried out during a period of north to NNW winds at 10 m.p.h. On this occassion there was a slight onshore breeze at stack height which caused a plume reversal as the smoke passed through a wind shear into the northerly flow. This results in a plume traverse at a distance of 'minus one mile' as shown for pass number 14 in Table 4.5. Figure 4.12 shows the location of the flight lines and a vertical elevation through the plume. In Figure 4.13 a virtual source has been postulated at a location represented by 3-1/2 miles, ie 3-1/2 miles upwind of the stack, and the values for traverse 13 and 14 have been halved since they appear to represent passes through the double plume.

TABLE 4.5

NO_2 - GULF OIL

OCTOBER 31, 1968

Pass No	Trace Length Cms.	Path Length M	Peak Ht. Cms.	NO_2 ppm-M	Area Cm^2	NO_2* ppm/M^2	Distance Miles
1	6.1	1750	1.5	11.6	6.4	22.7	1
2	8.9	2560	1.4	10.9	6.0	21.2	3
5	22.5	6460	1.6	12.4	20.4	72.0	12
6	20.5	5890	1.7	13.2	20.0	70.0	15
7	7.1	2040	2.0	15.5	6.7	23.8	13
10	11.0	3160	1.1	8.5	6.3	22.3	6
11	9.1	2610	1.3	10.1	7.5	26.5	3
12	6.2	1780	0.9	8.2	2.9	10.2	1
13	3.5	1000	2.8	21.8**	5.3	18.7	0
14	5.2	1490	3.3	25.6**	7.1	25.0	-1

* Divided by the "m" factor

** Divided by 2 for reversed plume

TABLE 4.6

SMOOTHED WIDTH AND BURDEN DATA

Pass No	Distance from virtual Source Miles	Width M	Burden ppm-m	$ppm\text{-}m^2$* x 1000
1	4	1600	10.5	6.8
2	6	2400	9.0	13
5	15	5700	12	34
6	18	6800	14.5	49
7	16	6000	13	47
10	9	3500	8.5	16
11	6	2400	9.0	9.8
12	4	1600	10.5	11
13	3	1200	11.5	7.3
14	2	800	13.5	7.5

*Divided by the 'm' factor

The raw data from Table 4.5 is plotted in Figure 4.13 and smoothed values from this figure are used as a basis of the adjusted data in Table 4.6 and Figure 4.14. Figure 4.14 shows a continuous increase in NO_2 burden but even after smoothing, the scatter is still too great for the form of the curve to be determined with confidence.

4.6 COMPARISON OF AIRBORNE AND IN-STACK NO_2 MEASUREMENTS

The steady operation of the generating station permits a direct comparison of the quantity of oxides of nitrogen measured from the air with a calculated quantity based on a stack analysis.

Under steady base load conditions, the fuel rate is 100 tons/hr per boiler, and with about 3% excess oxygen, the total flue gas is 1350 tons per hour per boiler. The wet chemical measurements, together with relevant facts gathered for the period under examination, are shown in Table 4.7.

FLIGHT I AUGUST 27, 1968

Flue Gas Oxides of Nitrogen = 190 ppm

Boilers on line 5

Therefore NO_2 potential

$$= 1350 \times 5 \times 190 \times 10^{-6} \times \frac{46}{29} = \text{T/hr}$$

$$= 1350 \times 5 \times \frac{190}{60} \times 10^{-6} \times \frac{46}{29} \times \frac{2000}{2.2} \times \frac{1}{2.06} \quad \text{M}^3/\text{min}$$

$$= 14.9 \text{ M}^3/\text{min}$$

Aircraft measured maximum NO_2 rate = **14.5** M^3/min

FLIGHT II SEPTEMBER 30, 1968

Flue Gas Oxides of Nitrogen = 390 ppm

Boilers on line 5

NO_2 potential $= 1350 \times 5 \times \frac{390}{60} \times 10^{-6} \times \frac{46}{29} \times \frac{2000}{2.2} \times \frac{1}{2.06} = 28.3\ M^3$

Aircraft measured maximum NO_2 rate = 22.3 M^3/min.

FLIGHT III - OCTOBER 31, 1968

Owing to the diverse nature of the sources and the lack of analytical data for many stacks, no estimate of the NO_2 production is possible.

TABLE 4.7

WET CHEMICAL ANALYSIS OF LAKEVIEW POWER STATION STACKS FOR OXIDES OF NITROGEN

DATE 1968	TIME	EXCESS AIR AS % O_2	FURNACE TEMP. °F	NO_x AS NO_2 ppm
August 27	14:30	3.5	560	190
Sept. 4	14:30	4	630	400
12	15:00	4	630	720
12	16:30	3.5	630	530
17	16:00	3.5	635	490
18	15:00	3.7	640	460
19	14:40	3.7	635	410
25	10:00	3.7	635	410
30	14:00	3.5	625	390

4.7 THEORETICAL ASPECTS OF PLUME DISPERSION

The behaviour of a plume under the influence of turbulence of the wind has been examined by numerous workers who have derived formulas to relate concentration with distance from the stack. A formula which is widely used, was developed by Pasquill (Ref 7) and takes the form

$$\chi = \frac{KQ}{\sigma_y \sigma_z \mu} * \exp -\tfrac{1}{2} \left(\frac{y}{\sigma y}\right)^2 * \left[\exp -\tfrac{1}{2} \left(\frac{H-Z}{\sigma_z}\right)^2 + \exp -\tfrac{1}{2} \left(\frac{H+Z}{\sigma_z}\right)^2\right] \qquad (1)$$

χ = concentration

where Q = quantity emitted

μ = wind velocity

x = direction along the wind

y = direction across the wind

z = vertical direction

and H = height of emission

The aircraft during its flight effects a vertical integral of the concentration and the vertical burden (B_z) is given by

$$B_Z = \overset{Z=\infty}{\underset{Z=o}{\quad}} \chi \; d_Z \qquad (2)$$

$$= \frac{k'Q}{\sigma_y \mu} * \exp -\tfrac{1}{2} \left(\frac{y}{\sigma_y}\right)^2 \qquad (3)$$

(See reference 8.) For temperatures somewhat above atmospheric, such as would exist in a stack and with low concentrations of NO in atmospheric oxygen, the rate constant is approximately 2×10^{-4} per pphm per hour. At a point about 1 mile from the stack where the flue gas has been diluted 1000 times by air, the concentration of nitric oxide has been reduced to 200 pphm and the rate of disappearance of nitric oxide will be proportional to the square of the nitric oxide concentration and equal to about 8 pphm per hour. This reaction is obviously far too slow to account for the rate of production of nitrogen dioxide as observed by the airborne sensor.

The rate of reaction of nitric oxide with ozone to yield nitrogen dioxide and molecular oxygen is approximately 10,000 times faster than the reaction of nitric oxide with oxygen. Provided therefore sufficient ozone is available to react with the nitric oxide, the reaction could be substantially complete in a period of an hour.

It has already been established in studies in connection with oxidant damage to tobacco crops in South Western Ontario, that the air mass associated with an anticyclonic high pressure system and south westerly winds contains the remnants of a well aged photochemical smog with ozone levels of up to 10 pphm. It is probably also significant that for the run of Sept. 30th where the plume passes through a wind shear into a south westerly air flow, that nitrogen dioxide is generated at a high rate and that the maximum quantity of NO_2 is obtained within a period of about 1.5 hours.

The flight for Sept. 30th also shows a progressive decrease in the burden of NO_2 and the maximum value of the integral during any traverse occurs where $y = o$ and is given by

$$B_Z \text{ (max)} = \frac{K' Q}{\sigma_y \mu} \qquad (4)$$

Therefore the decay in NO_2 concentration after its formation is substantially complete will vary as $\frac{1}{\sigma y}$.

Table 4.8 shows the concentrations calculated from equations (4) above compared to with the actual measurements.

Column 3 shows the value of σ_y at various distances, and column 4 shows the ratio of σ_y' (x) to σ_y(6Km). Column 5 shows the measured values of χ at various distances and Column 6 shows the ratio of χ (x) to χ (6 Km). If equation (4) holds, the product of columns (4) and (6) shown in column 7, should be constant. The theoretical decay values predicted by equation (4) and based on the value of $\chi = 34$ at 6 Km are given in column 7. These values suggest that although the maximum burden exists at 6 miles, the decrease is less than theoretical up to 18 miles and faster than the theoretical exponential rate after 18 miles. The additional NO_2 over that predicted by theory for 6 to 18 mile section is presumably due to continued production of NO_2 while the reaction rate is decreasing due to exhaustion of the nitric oxide. The defecit of NO_2 between miles 18 to 25 suggests that NO_2 is entering into further reactions and is being destroyed in this region.

The rate constant for the reaction $NO_2 + O_3 = NO_3 + O_2$ at a value of about .05 pphm^{-1} hr^{-1} at ambient temperature and while this reaction rate is several orders lower than the reaction of ozone with nitric oxide, the reaction is nevertheless still fast enough to be important, for example, with nitrogen dioxide and ozone at 10 pphm each, the rate of reaction will be about 5 pphm per hour or a decrease of about 30% per hour. Thus, at least in terms of orders of magnitude the data obtained by these airborne surveys is consistent with the oxidation of nitric oxide and nitrogen dioxide by ozone to NO_3.

TABLE 4.8 THEORETICAL DECAY OF PLUME CONCENTRATION

χ miles	Km	σ_y	$\frac{\sigma'_y}{\sigma_y}$	χ_n	$\frac{\chi_x}{\chi_{max}}$	$\frac{\chi_x \sigma'_y}{\chi_{max} \sigma_y}$	Theor. χ_n
6	10	850	1.00	34	1.00	1.00	34
10	16	1300	1.53	29	.85	1.30	22
14	23	1700	2.00	24	.71	1.42	17
18	29	2200	2.60	20	.59	1.53	13
22	36	2600	3.10	13	.38	1.18	11
25	40	2800	3.33	9	.26	0.86	10
30	48	3400	4.00	7	.205	0.82	9

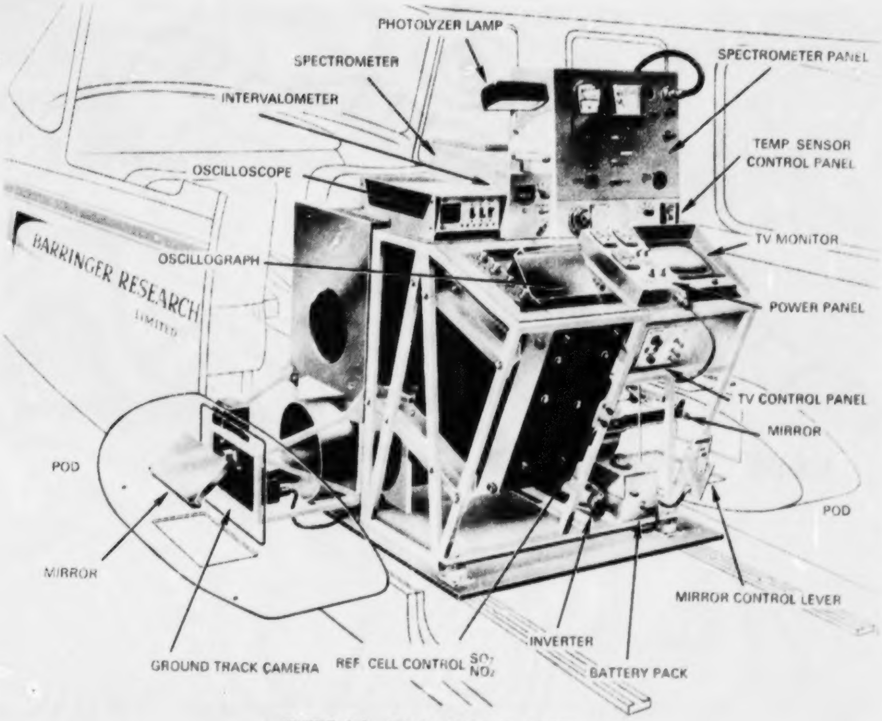
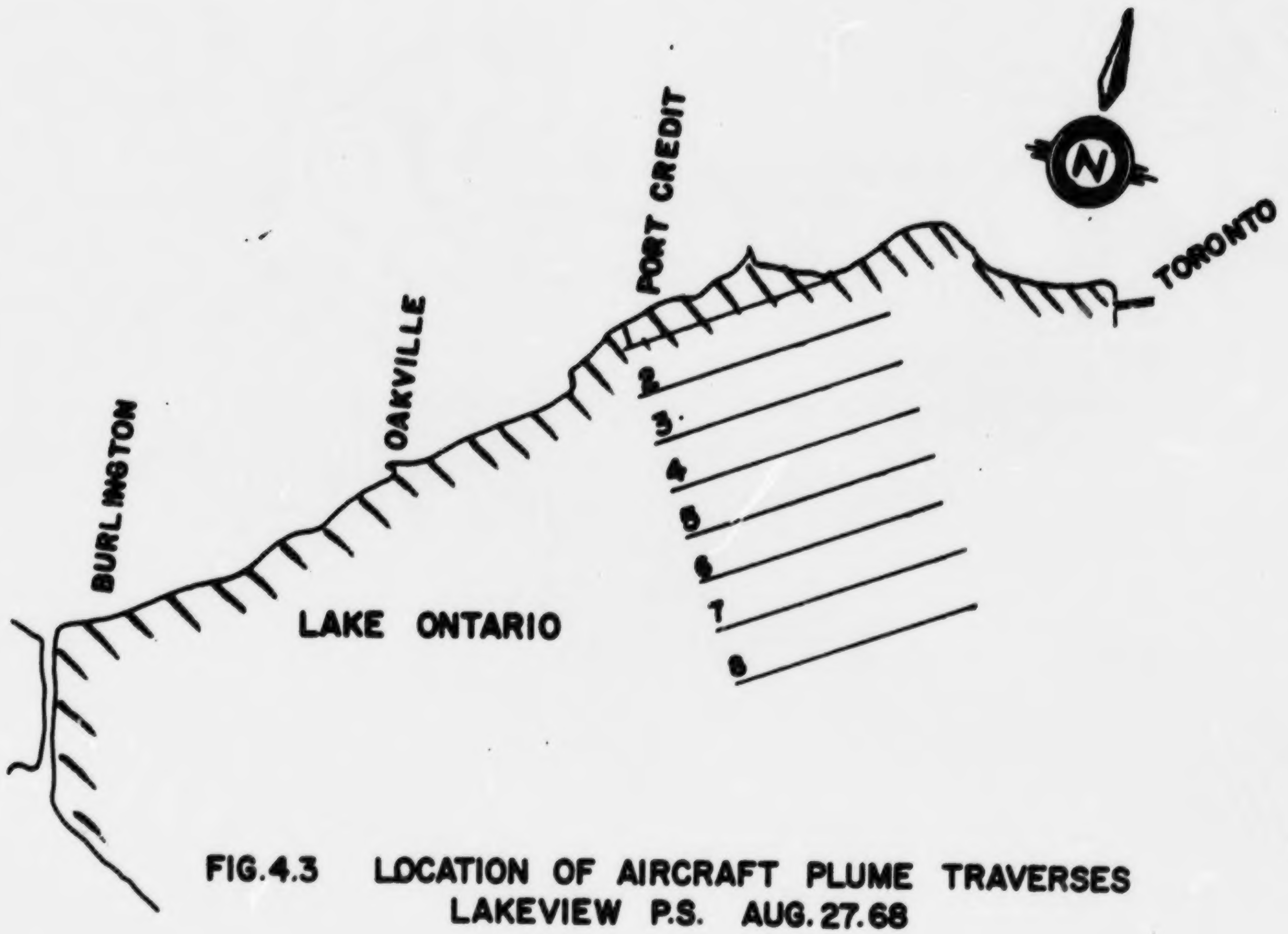

PHOTOLYZER LAMP
SPECTROMETER
SPECTROMETER PANEL
INTERVALOMETER
TEMP SENSOR CONTROL PANEL
OSCILLOSCOPE
TV MONITOR
BARRINGER RESEARCH LIMITED
OSCILLOGRAPH
POWER PANEL
TV CONTROL PANEL
MIRROR
POD
POD
MIRROR
MIRROR CONTROL LEVER
INVERTER
GROUND TRACK CAMERA
REF. CELL CONTROL SO_2 NO_2
BATTERY PACK

FIGURE 4.1 INSTALLATION OF AIRBORNE CORRELATION SPECTROMETER IN AEROCOMMANDER AIRCRAFT

FIGURE 4.2 AEROCOMMANDER AIRCRAFT



PORT CREDIT
TORONTO
OAKVILLE
BURLINGTON
LAKE ONTARIO
N
2
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4
5
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7
8

FIG.4.3 LOCATION OF AIRCRAFT PLUME TRAVERSES LAKEVIEW P.S. AUG.27.68

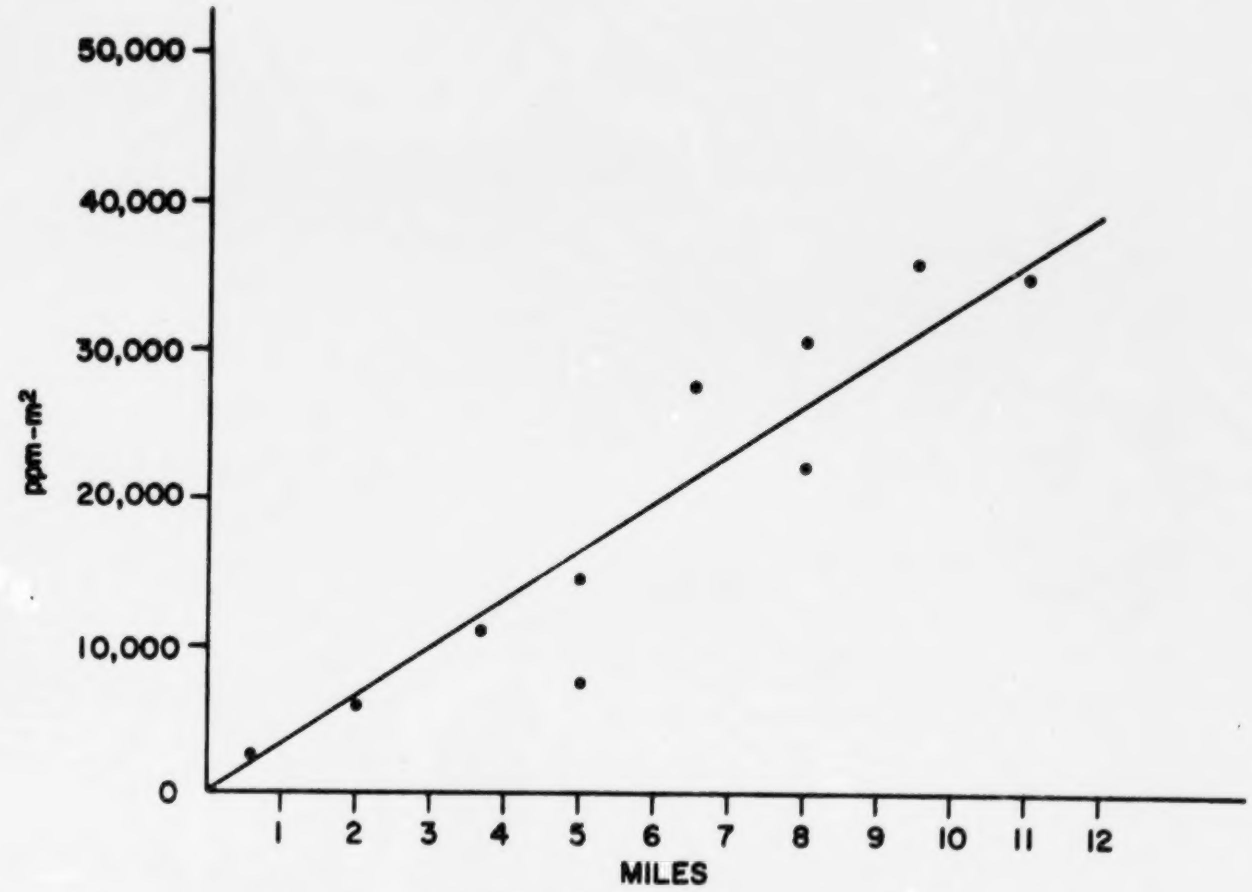


FIG 4.4 NO_2 BURDEN IN ppm-m^2 VARIOUS DISTANCES LAKE VIEW G.S. AUG. 27, 1968

AUG. 27, 1968 NO₂ PLUME LAKEVIEW

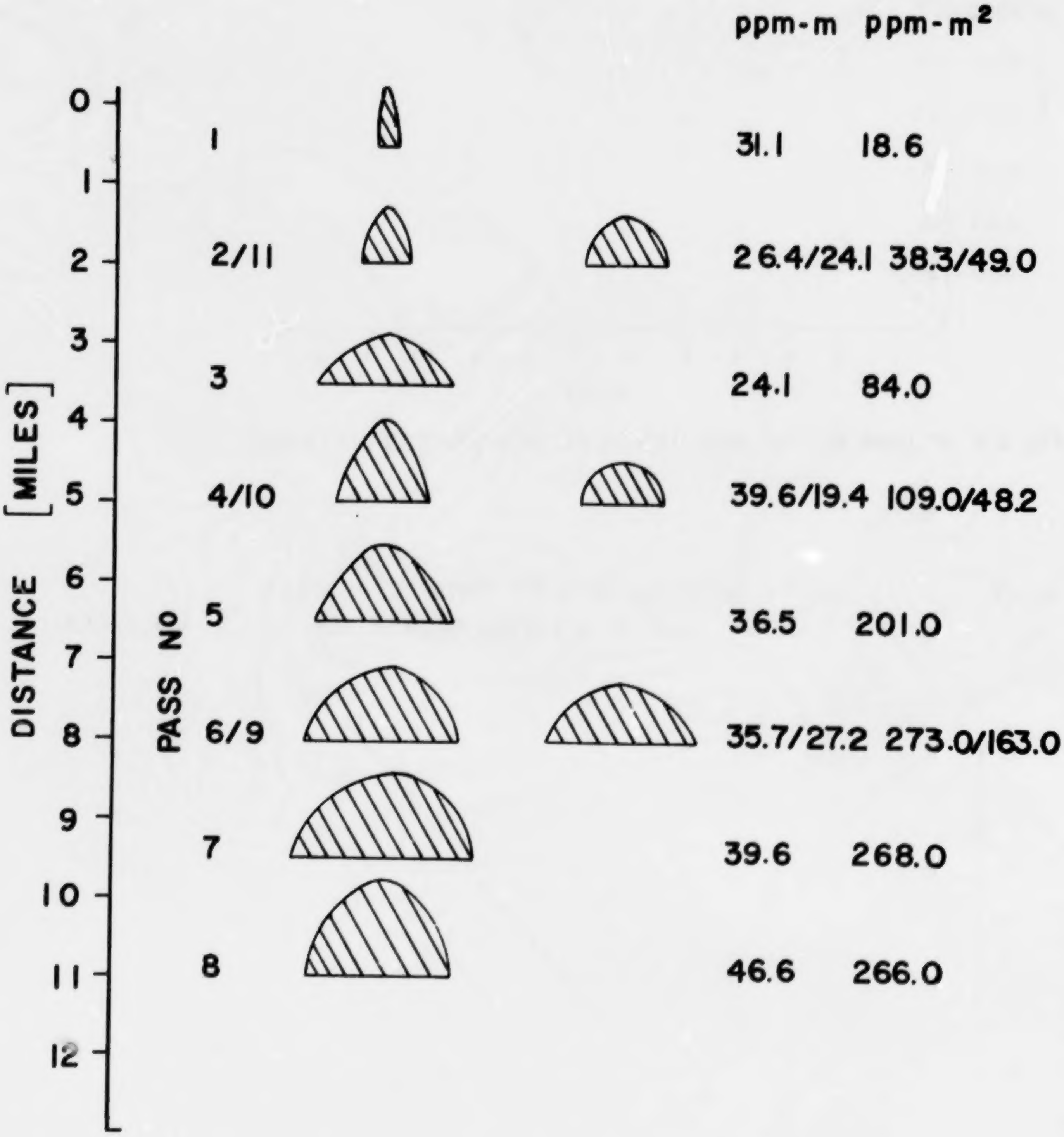


FIG 4.5 RELATIVE PLUME CROSS-SECTIONS
(SIMPLIFIED SHAPE)

SCALE 0.1" = 1cm.

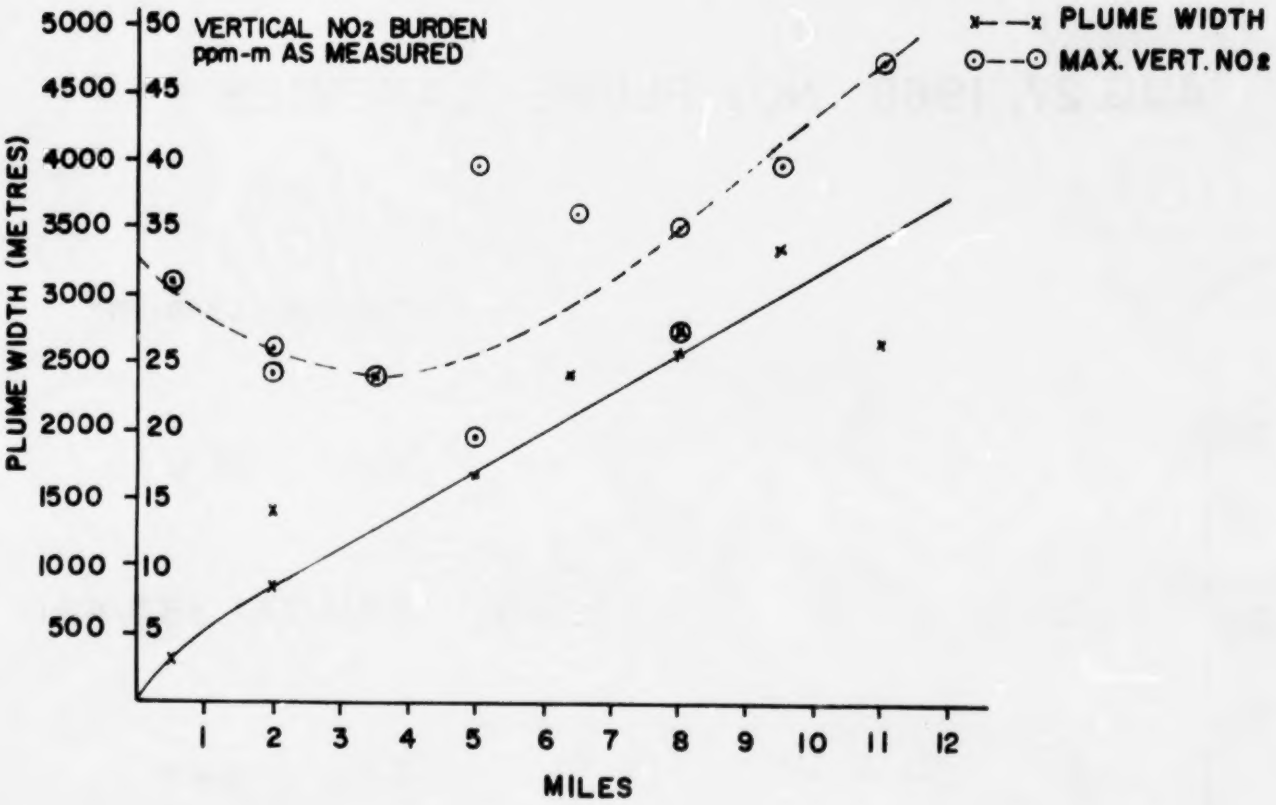
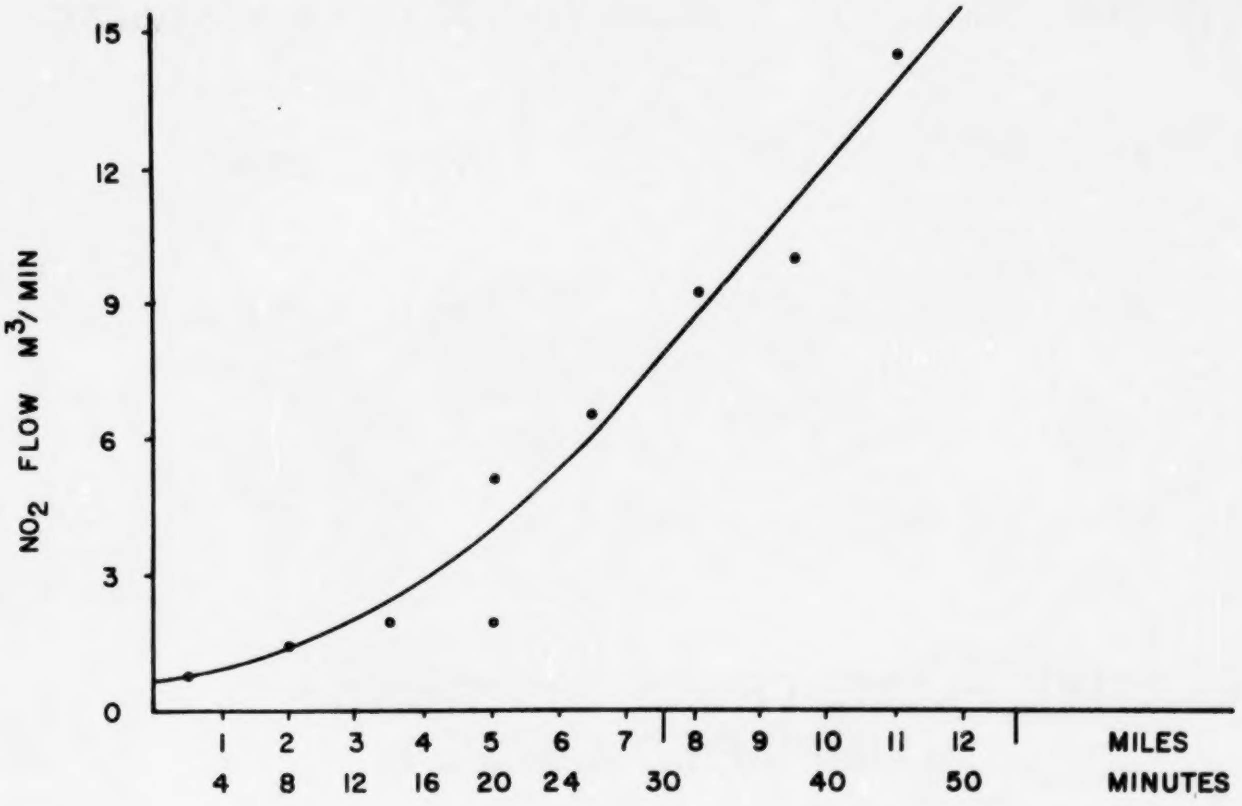


FIG 4.6 PLUME WIDTH AND VERTICAL NO_2 VERSUS DISTANCE

FIG. 4.7 NO_2 FLOW IN PLUME WITH DISTANCE IN MILES AND TIME IN MINUTES FROM STACK AUG. 27/68



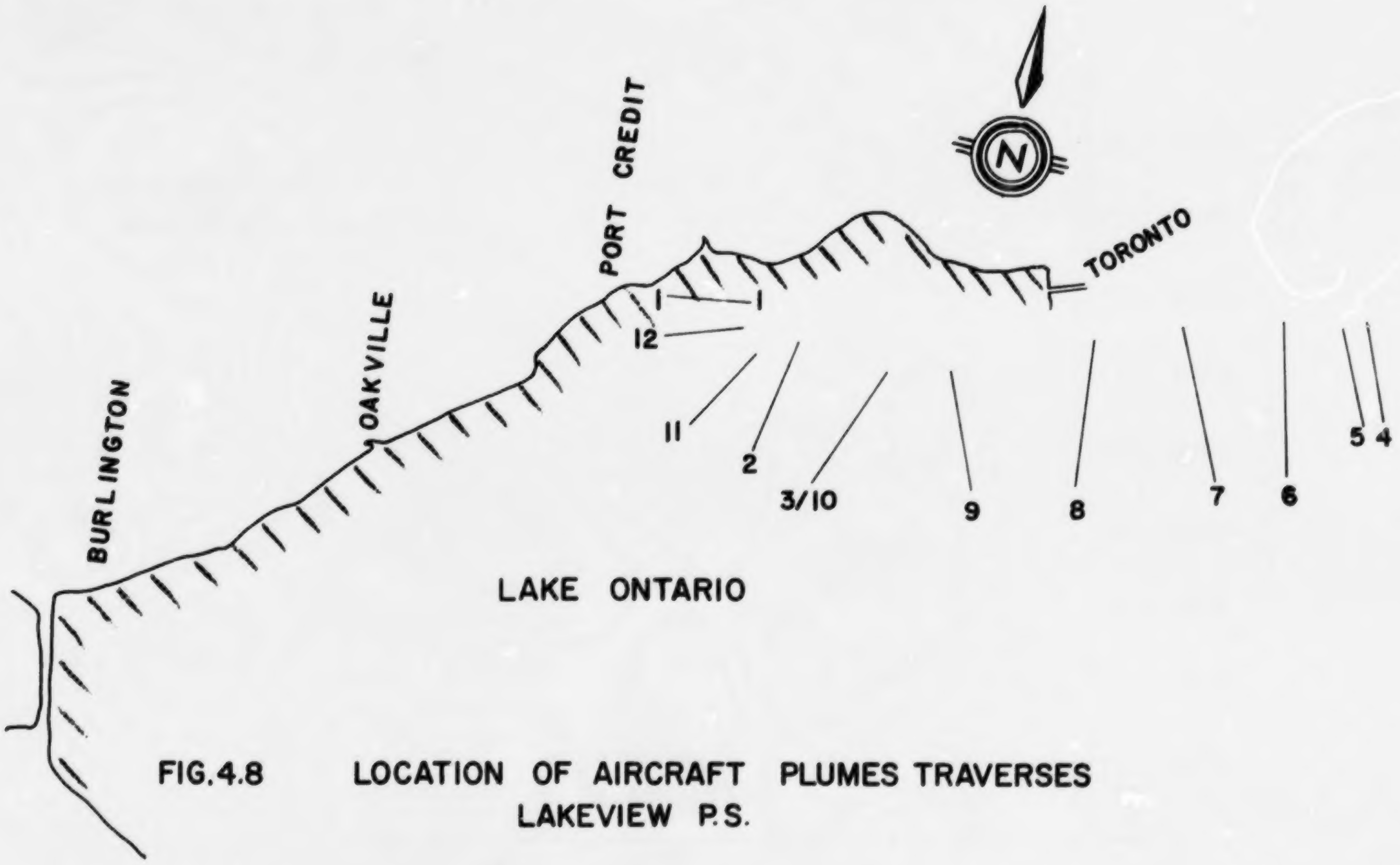

N
BURLINGTON
OAKVILLE
PORT CREDIT
TORONTO
1
1
12
11
2
3/10
9
8
7
6
5
4
LAKE ONTARIO

FIG.4.8 LOCATION OF AIRCRAFT PLUMES TRAVERSES LAKEVIEW P.S.

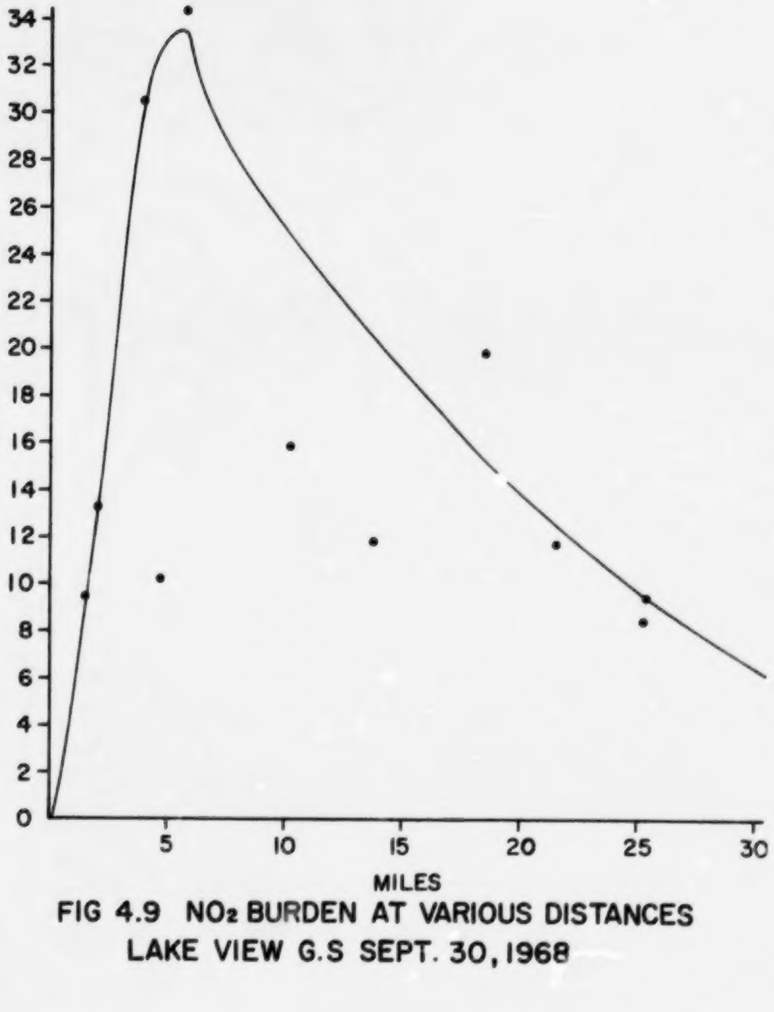


FIG 4.9 NO_2 BURDEN AT VARIOUS DISTANCES LAKE VIEW G.S SEPT. 30, 1968

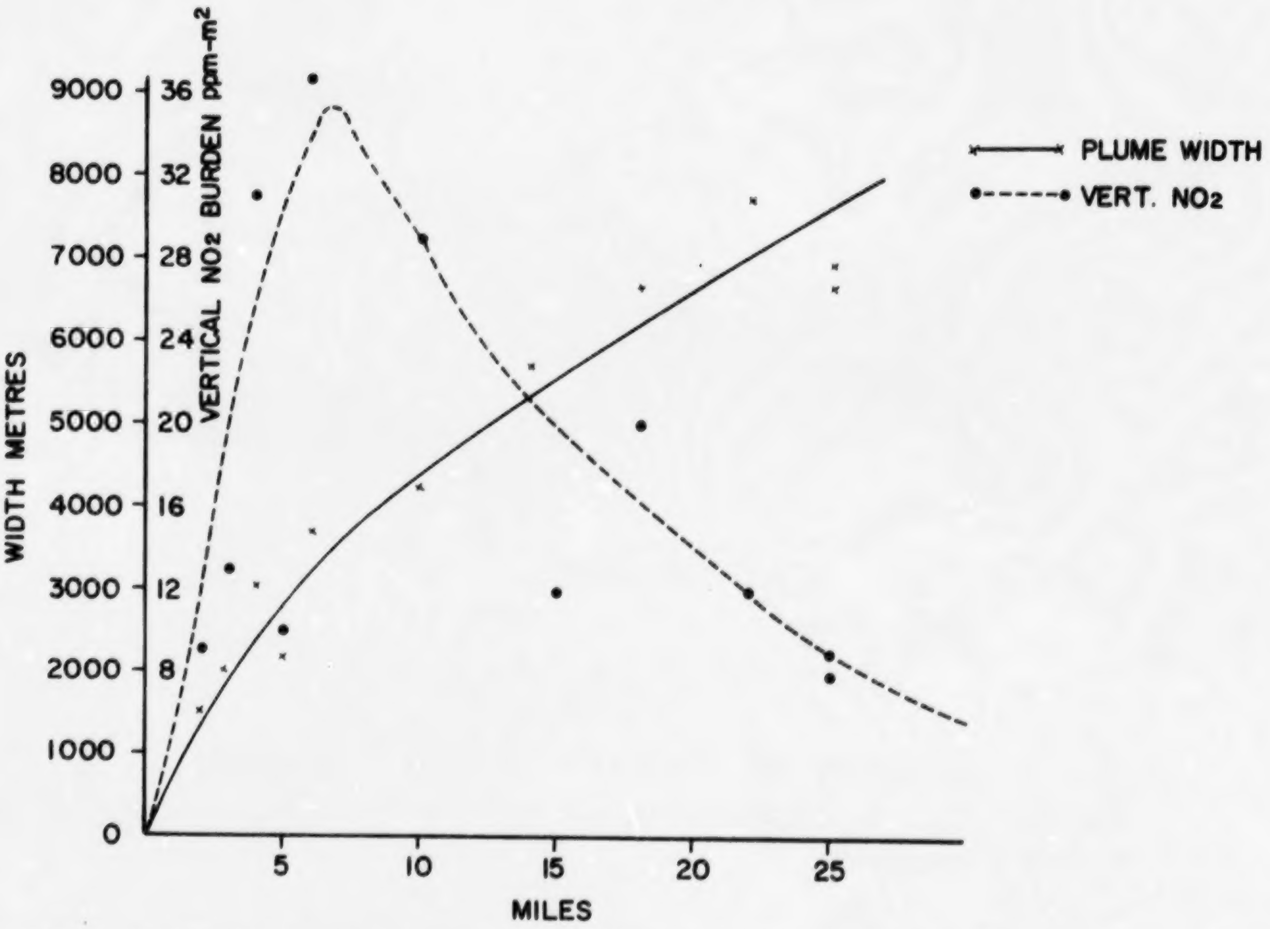
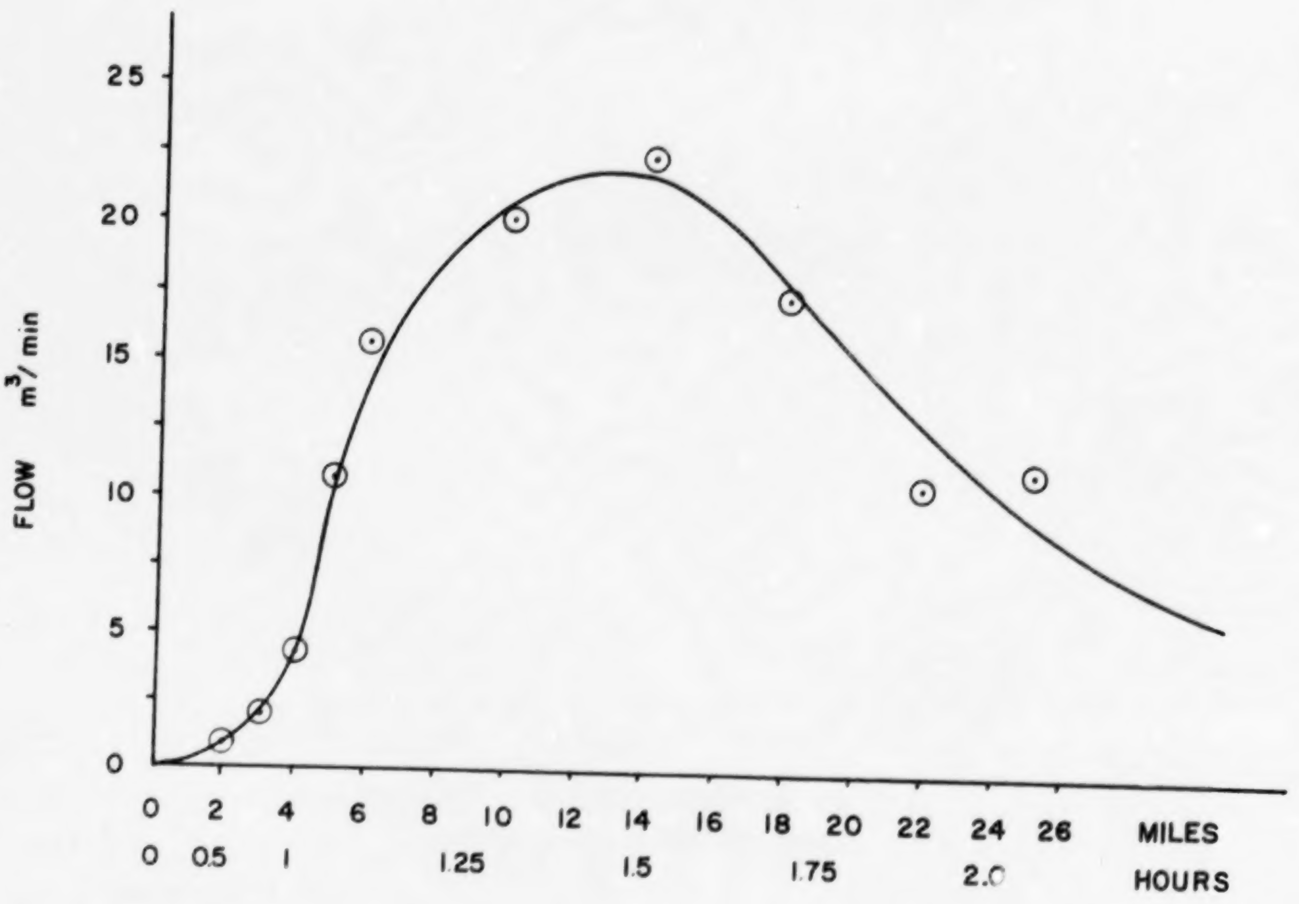


FIG 4.10 PLUME WIDTH AND PEAK VERTICAL NO$_2$ VERSUS DISTANCE

FIG. 4.11 CORRECTED NO$_2$ FLOW



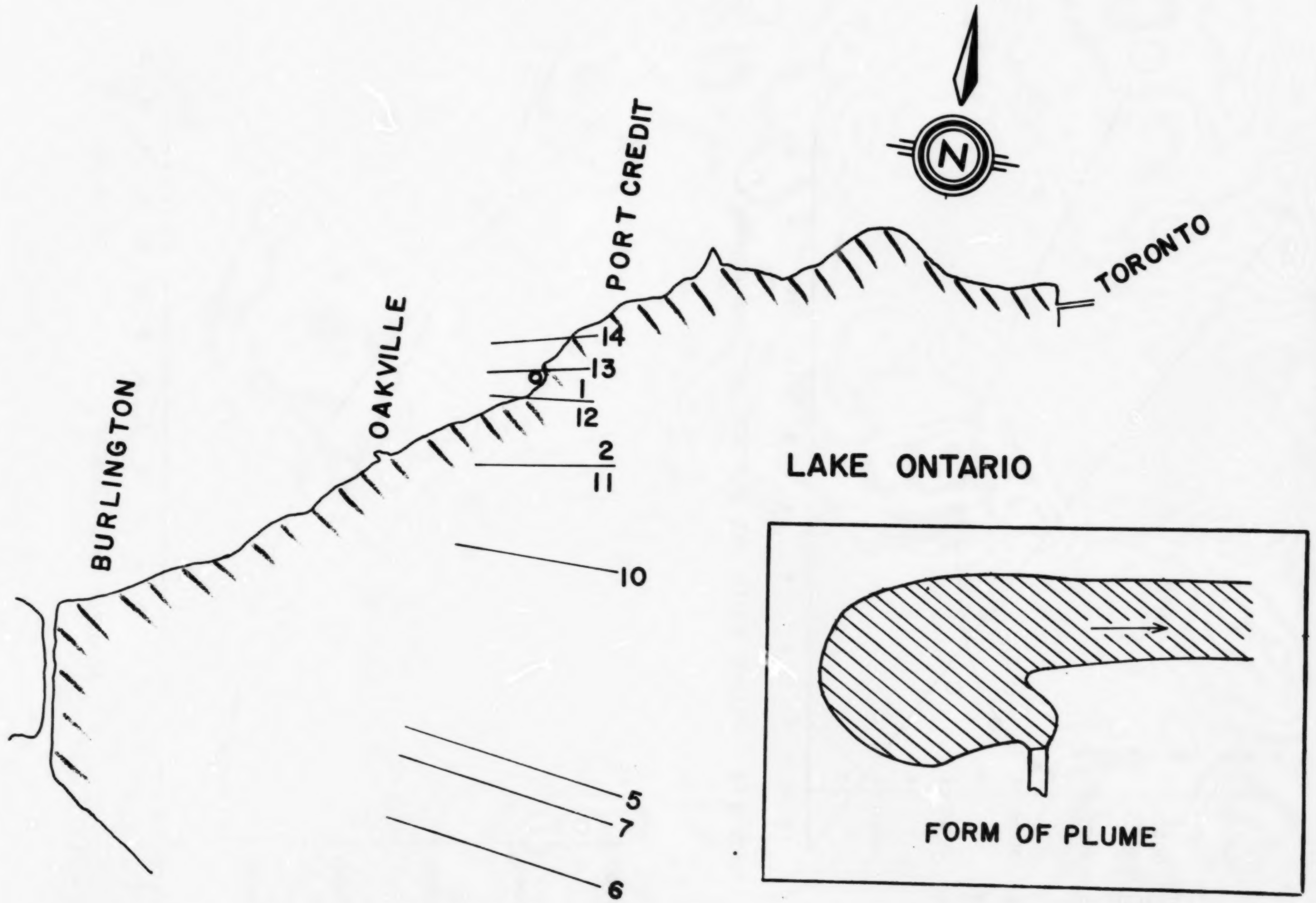

N
TORONTO
PORT CREDIT
OAKVILLE
BURLINGTON
14
13
9
1
12
2
11
10
5
7
6
LAKE ONTARIO
FORM OF PLUME

FIG. 4.12

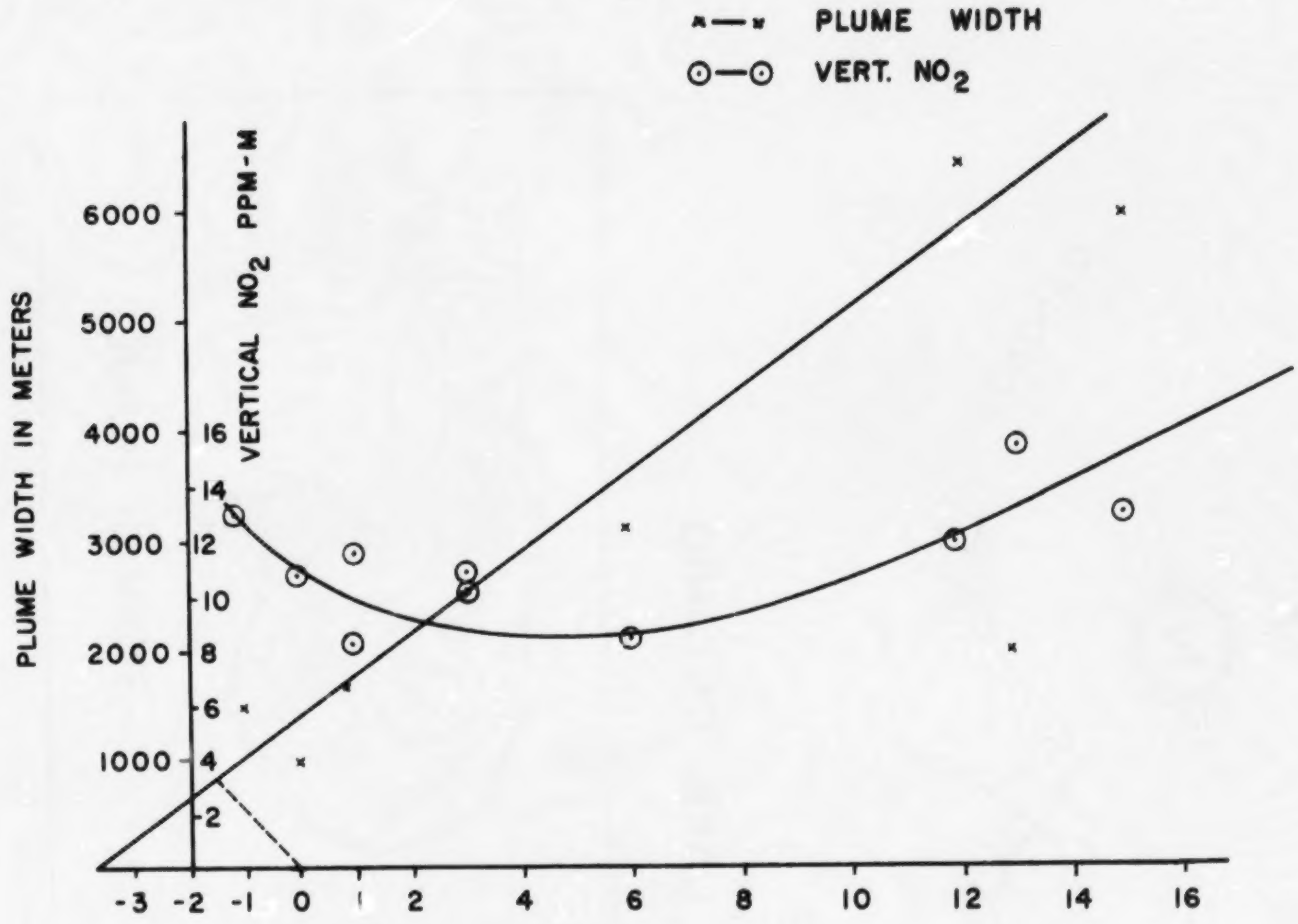


FIG 4.13 PLUME WIDTH AND VERTICAL NO_2 VS DISTANCE

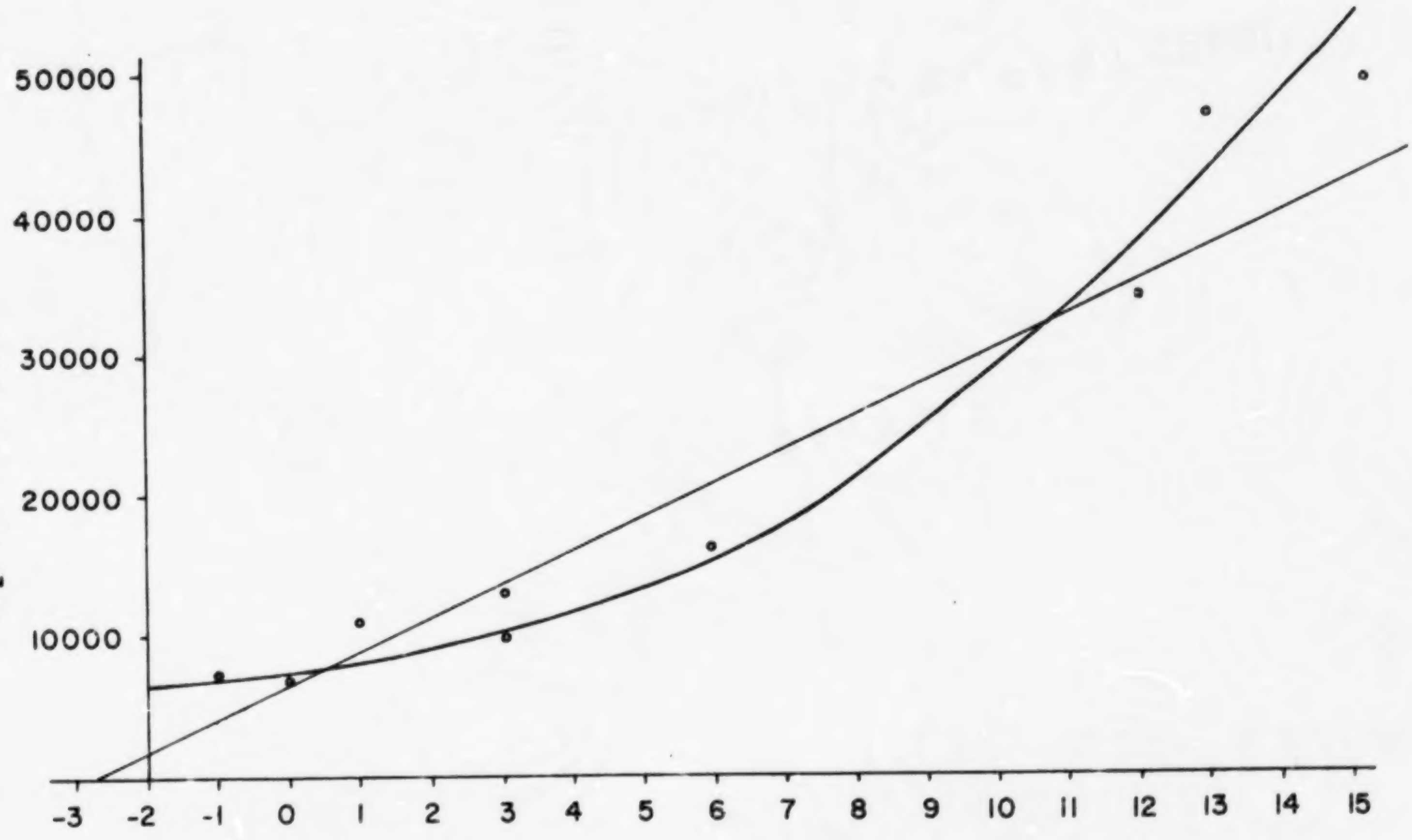


FIG 4.14

Section 5

PHASE III

5.1 OBJECTIVES

The objective of Phase III was to compare the sulphur dioxide measurements of the point sampler with those obtained for the long Path Sampler. Various long paths were used and the complete work was conducted in a typical urban environment. It was thought that the long path sampler would provide readings more representative of the ambient sulphur dioxide concentrations in the urban environment since they were averaged over a considerable distance.

For a long path sampler, there is a limiting short pathlength at which its data does not differ significantly from that produced by a point sampler. This will occur when the limiting short pathlength is representative of the local ambient air immediately available to the point sampler. Conversely, there is a limiting long path length determined by the instrument noise resulting from the decrease in signal energy as the pathlength is increased. Thus, an additional objective of this programme was to determine these minimum and maximum pathlengths for significant averaging by the long path sampler. Additional information was also sought on the accuracy of the samplers by the simultaneous operation of a wet chemical method and a commercially available coulometric sulphur dioxide analyzer.

5.2 TEST SITE

The test site chosen was an open field in Etobicoke, on the western side of Toronto, Ontario. The site was located between Evans Avenue to the south, the Queen Elizabeth Way to the north and just east of Kipling Avenue. This location is in the suburban west end of Toronto about one mile from the shore line of Lake Ontario. This is an area of intense development of small factories and is subject to only minor sources of SO_2 pollution except for a major power station about 5 miles to the southwest. The site was chosen because it contained an air pollution test facility of the Ontario Government and also its open location permitted easy line-of-sight for the long path monitor. Its location promised frequent inversions in the air flowing off the cold waters of Lake Ontario.

The dominant feature of the site is a meteorological tower carrying three Bendix aerovane anemometers and it was the opinion of the Government's meteorologist that the trailers which housed our monitors should be parked at least 50 yards from the base of the tower so that the wind trajectory to the aerovanes would not be disturbed. The trailers were therefore parked near the south boundary and about 50 yards from the base of the tower. At the tower's base was a small hut which housed the Beckman SO_2 analyzer, and thereby allowed a comparison with an accepted commercial instrument.

5.3 INSTRUMENTATION

The Point Sample Ambient Monitor (Figure 5.1) has been designed as an alternative to the commercially available coulometric or conductometric continuous analyzers. Definitive air quality criteria now being formulated call for maximum concentrations of 50, 25 and 5 pphm of SO_2 and NO_2 for one hour, one day and one month exposure periods respectively. The point sample ambient monitor was therefore designed for a detection limit of 1 pphm with a time constant of 100 seconds. This led to the selection of a double pass optical cell 1.25 meters long which thus gives an absorption path length of 2.5 meters; the correlation spectrometer itself encloses the absorption volume (Figure 5.2). The absorption bands of SO_2 and NO_2 are sufficiently regularly spaced that multiple entrance slits can be used, leading to a high light throughput and hence an improved signal-to-noise ratio. Modulation of the spectrum was one of the major problems of the entire development. In a high sensitivity system, the requirements for a suitable modulator are stringent in that they should not contribute to random noise, nor must they generate coherent noise which can result in zero offsets. The system chosen uses a torque motor to vibrate the grating and a feedback control maintains the exact amplitude and mean position. The electronic block diagram is shown in Figure 5.3.

The signal channel uses an R.C. amplifier filter synchronous detection system and a low pass filter that drives a standard 100 millivolt recorder. An automatic eletronic re-zero circuit operates at fixed intervals to correct any zero drifts. Sensitivity to the ambient temperature has been a problem, but where the equipment is used in an air conditioned environment with the additional advantage of the automatic zero reset circuit, the effect of this drift on the operation of the instrument has been insignificant. However, we feel that an extended temperature range should be available and it is hoped to reduce the temperature sensitivity of the instrument from the present 3 ppb per ^{o}F to 0.3 ppb per ^{o}F.

The Long Path Ambient Monitor is a modification of the remote sensor in which an active light source is positioned some distance away from the sensor and thereby, the pathlength is physically defined. To permit operation during the day light hours, a mechanical light chopper shown in Figure 5.4 provides 100% modulation of the source at 2400 Hz and the spectrometer signal is processed to recognize signals synchronous with this modulation. Early tests were carried out with a 3400^{o}K quartz-iodine lamp which had a pathlength limit of about 500 meters. Further tests using a xenon arc source indicated that pathlengths up to 1500 meters could be successfully used.

One essential difference between the long path ambient monitor and the remote sensing spectrometer is the inclusion of a scanning device to produce a low speed oscillation of the spectrometer grating. This device,which is considered in detail in the theoretical treatment in reference 2, displays the change in correlation as the spectrum is slowly swept across the fixed mask from the correlation to the anti-correlation position. Measurement of the difference in output between correlation and anti-correlation is a direct measure of twice the correlation signal and minimizes zero offsets arising from changes in the spectral slope of the light caused by variations in the light source or diffential absorption by gaseous interferences or particulate matter in the atmosphere.

For the short pathlengths, the spectrometer was housed in a trailer placed alongside the Point Source Ambient Monitor trailer at the south side of the site and the modulated light source was set up near the northern boundary. For the intermediate pathlength, the light source was moved northward to the roof of a factory building across the Queen Elizabeth Way (a 12 lane freeway). For the long path length the trailer was moved to a new location about 600 metres south, while the light source remained on the factory roof.

A Coulometric Analyser is operated at the site by the Ontario Provincial Government as a part of their air pollution measurement network. This instrument measures the flow of electricity necessary to maintain a selected iodine level in a reaction cell by electrolysis of an iodide solution as the iodine level is depleted by reaction with atmospheric sulfur dioxide. The instrument was operated by Government scientists; calibrated and serviced according to their normal routine. By arrangement with the Air Pollution Control Dept. of the Department of Health, photostatic copies of their charts were made available to us as they were processed by the department.

Wet Chemical Analyses were carried out manually at frequent time intervals using the West Gaeke Procedure. To monitor the performance of the PSAM, the samples were collected from a point near the inlet tube of the monitor. For evaluation of the LPAM, the wet chemical equipment was installed in an automobile and a spatially integrated sample collected by driving as close to the optical path between the long path sensor and the remote light source as geographical conditions would permit. The West Gaeke procedure consists of bubbling air at a known fixed rate for a selected time period through a solution of sodium tetrachloromercurate. For field work, the chloromercurate solution is measured into a midget impinger and a flow rate of two litres per minute is set on a lucite flowmeter using a freon powered ejector or alternatively a 1.5 cu. ft. evacuated bottle as a source of suction. Formaldehyde solution and an acid bleached pararosaniline hydrochloride dye are added to the aspirated chloromercurate and the intensity of the colour developed is compared spectrophotometrically with known standards. This technique has a sensitivity of 10 ppb of SO_2 using 10 mls of chloromercurate as a sampling solution in conjunction with a 50 litre air sample.

5.4 EXPERIMENTAL PROCEDURE

The field programme ran for a period of 14 days. The point sample ambient monitor was operated in the trailer at the south side of the field. Simultaneously, the Beckman Coulometric analyzer was operated in the hut at the meteorological tower. During this period the long path ambient monitor was first operated at a path length of 100 meters for a four day period; at an intermediate path length of 300 meters for a further four days; and at a long path length for three days. The short and intermediate pathlength experiments were carried out using a 500 watt 3400°F quartz-iodine lamp. Attempts to increase the path length beyond 500 meters using this light source were unsuccessful since beyond this range the energy recieved by the spectrometer was insufficient to maintain a satisfactory signal/noise ratio. The quartz-iodine lamp was replaced with an xenon-arc resulting in a considerable increase in energy transmitted to the spectrometer and consequently an operating pathlength of 930 meters was selected.

During the early part of the test, wet chemical analyses were carried out at frequent intervals on a routine basis. Subsequently, wet chemical analyses were suspended and instituted only when the monitors indicated an increase in the SO_2 content of the atmosphere.

5.5 RESULTS

5.5.1 Point Sample Ambient Monitor Versus Long Path Ambient Monitor

As with most urban air pollution data the results of the tests carried out at the Evans Avenue site show long periods of relatively low pollution levels. For the purposes of this study three periods were selected, one for each of the pathlengths, namely 100 meters, 300 meters and 930 meters. These periods were selected to contain most of the high peaks as well as periods of low pollution in order to cover the full dynamic range of the instruments. Having confirmed that the readings of the two monitors were time synchronized, exact readings were taken from the records at intervals of about 2 minutes. These values were multiplied by their respective calibration factors and were entered into an IBM 7044 computer. The library programme STATPK was used to draw scatter diagrams and calculate the correlation coefficient, regression coefficient and the intercept. In each of the studies detailed in 5.5.1 below, the point sample ambient monitor was arbitrarily chosen to be the independent variable plotted on the x axis.

RESULTS OF 100 METER PATHLENGTH TESTS

A four hour period containing a moderately sized peak was chosen for this pathlength. Figure 5.5 shows the computer generated scatter diagram. At this short pathlength the sensitivity of the instrument is low with a calibration factor of 19.4 ppb per scale division, and the recording facility read only to the nearest division. The statistically derived data are:

Correlation Coefficient............	0.909
Regression Coefficient.............	0.826
Intercept..........................	87.72

Despite the low resolution of the long path instrument at this relatively short pathlength, the correlation is good. The regression coefficient indicates a discrepancy in the calibration factors of one of the instruments. The intercept indicates that the long path monitor has a zero offset of about 5 divisions (87.7/19.4 = 5 divisions).

LONG PATH - 300 METERS TESTS

An 8 hour period was selected for this correlation containing two peaks of over 200 ppb each. The readings were digitized at a rate of 11 points per hour to cover the whole period within the 100 data point limitation of the computer. Figure 5.6 shows the plot of both samples for a two hour period illustrating how the two curves move in unison.

Figure 5.7 shows the scatter diagram for this period. The 2 black squares define the origin and the line for a unit regression coefficient. The derived data are:

Correlation Coefficient 0.970
Regression Coefficient 0.898
Intercept 60.19

The correlation at this pathlength is very good. The calibration of the point-sampler again appears to be lower than that for the long path. The calibration factor of the long path instrument is 6.5 ppb per division and the zero offset at this pathlength is about 9 divisions.

LONG PATH - 930 METER TESTS

At this pathlength a xenon arc light source was substituted for the quartz iodine lamp which had insufficient power to operate at pathlengths in excess of 500 meters. For this pathlength, two consecutive four hour periods were selected each containing good peaks. Both were digitized at 22 points per hour. Some points were lost during periods when the Point Sampler was being calibrated and also the resolution of the diagram is such that two very close points are plotted as one. Figure 5.8 shows the computer generated scatter diagram for the first period which gave the following statistical values.

Correlation Coefficient........ 0.951
Regression Coefficient 0.920
Intercept 18.92

The correlation coefficient is good and is in line with the coefficient for the shorter pathlengths. The regression coefficient is good and shows some improvement in calibration in comparison with the shorter pathlengths. The intercept remains at about 8 divisions.

The scatter diagram for the second 4 hour period is shown in Figure 5.9. It can be seen that there is an increase in the scatter of the points and the correlation coefficient is poor. The points circled represent consecutive readings ranging over thirty minute periods in which the long path seems to have registered a peak which was not detected by the point sampler. This is probably the explanation of the 2 points (x) which were also consecutive and were the last 2 points in the period. If the circled and x'ed points are disregarded, the statistical results become:

Correlation Coefficient	0.095
Regression Coefficient	0.618
Intercept	40.57

The omission of the circled points result in an improvement in the correlation coefficient to the level previously obtained with other pathlengths. But the regression line is very different from that in the previous periods.

Of the three pathlengths, the best correlation is shown at 300 meters. For the 100 meter pathlength, the results are degraded by the low resolution of the instrument. For the 930 meter pathlength, the correlation is good only for short periods.

The apparently spurious points in figure 5.9 could have arisen from the presence of sulfur dioxide clouds existing within the light path of the long path monitor but distant from the point sampler. This variation in the quantity of sulphur dioxide intercepted by the long path instrument but not recorded by the point sampler results in variation in both the regression coefficient and the intercept. Over short periods however, when the atmosphere remains homogeneous the correlation coefficient could remain fairly high. It is expected, that this effect would be more frequent for longer pathlengths than for the shorter pathlengths.

As a corollary to the averaging effect of the long path, it is to be expected that readings taken at a point would reach higher and lower extremes than the integrated readings for the long path instrument. The effect of this would be to give a lower slope and regression coefficient and higher intercept. This fact may help to explain why in most cases the slope is less than 1. It may also contribute to the large zero offsets recorded.

It should be noted that there is a major coal fired power generating station located several miles from the test site and that looping of the plume from this source could cause considerable differences between point and long path readings. Other factors contributing to the scatter are:

(1) Distance between the point sampler and the light path of the long path sampler.
(2) Difference in the electronic time constants of the two instruments, namely 100 seconds for the point sampler ambient monitor and 1.5 seconds for the long path ambient monitor.
(3) Effect of zero or calibration drift in either instrument.
(4) Errors in time synchronization for selecting data points.

Within the limits of the field work all of these factors have been reduced to a minimum and they are not considered to be significant sources of error.

5.5.2 Point Sample Ambient Monitor Vs. Wet Chemical

In these studies the wet chemical results are arbitrarily taken as the independent variable and plotted on the x axis. Figure 5.6 is the computer generated scatter diagram for the point sample ambient monitor and the wet chemical analyses made in the vicinity of the point samples. The small black squares define the line for a regression coefficient of 1. All scales are in ppb of SO_2. The generated statistical data are:-

Correlation Coefficient............	0.823
Regression Coefficient.............	0.872
Intercept..........................	0.883

The correlation is acceptable but not good. The regression coefficient of 0.87 suggests that the point sample calibration is slightly low but the zero deviation of less than 1 ppb is extremely good.

5.5.3 Beckman Coulometric Vs. Chemical Method

Figure 5.7 is the scatter diagram and again all values are in ppb SO_2. The black squares define the line for the regression coefficient equal to 1. The point circled was taken to be spurious and excluded from the results, since none of the three monitors read SO_2 levels over 100 ppb while the wet chemical test was being performed.

These data show appreciable scatter and the correlation is poor. Under these conditions, the regression equation and intercept probably do not accurately reflect differences in calibration. However, since the wet chemical measurements were taken at a location about fifty yards from the Beckman instrument, most of the scatter must be attributed to the physical separation of the sample points and thus further points to the sensitivity of point samplers to their precise location.

The statistical data derived are:

Correlation Coefficient	.800
Regression Coefficient	.800
Intercept	9.00

5.5.4 Long Path Ambient Monitor Vs. Wet Chemical Methods

Figure 5.8 is a scatter diagram for the long path monitor versus the Wet Chemical analysis and includes 2 types of wet chemical analyses. The circled points are those for which the wet chemical sampler was moved between the light source and the sensor of the long path instrument close to, but not coincident with, the light path in order to simulate the space integrated sample. The remaining point represents stationary samples taken at the point sample ambient monitor location. The correlation for the integrated sample is some what better than for the stationary sample. The derived coefficients are:-

Correlation Coefficient	0.892
Regression Coefficient	1.071
Intercept	-0.443

There is a good correlation between these two monitoring methods. The regression coefficient and the intercept are close to ideal. It should be noted that an allowance of five divisions for the quartz iodine lamp and three divisions for the xenon arc lamp have been made in the zero offset. These are the values derived from the earlier study of a correlation between the point sample and long path ambient monitor. The very small intercept obtained here confirms the correctness of these allowances.

5.5.5 Point Sampler Vs. Coulometric Sampler

The correlation between these two instruments was carried out for a seventeen hour period. Since the entire set of data was too large to be stored in the computer, every third point was read in with allowance for the 18 ppb zero offset previously noted. The correlation for the whole period was found to be:-

Correlation coefficient	0.987
Repression coefficient	0.925
Intercept	0.20

5.5.6 Sliding Correlations

When statistical procedures are applied over long periods of time, average correlations are obtained which may conceal periods of very high or very low correlations. To investigate the change in correlation with time, a computer programme was set up to calculate the correlation and regression coefficients for batches of 40 points. The computer progressively discards five early results replacing them by 5 new results to give a continuous series of coefficients.

Figure 5.10 shows the sliding correlation for the Long path (930 metres) versus the Point Sampler. In the early part of the period, the slope approaches 1.0 and the intercept is small. During the middle of the period the correlation coefficient falls to below 0.3 and the intercept increases precipitously. Towards the end of the period under review, the correlation coefficient and slope again improve.

Figure 5.11 shows the sliding correlation for the Point Sampler and the Coulometric analyser. In this case, the slope is low for the early part of the period mainly due to noise during a period of very low gas concentrations. As the gas concentration increases, the slope goes through a maximum and settles to a value of 0.90.

5.6 DISCUSSION

The Long Path Ambient Monitor is the first practical instrument to measure over a long path length. At short pathlengths, the results are degraded by low signal/ noise ratios. As the path length is increased from 100m to 300m, the correlation coefficient against the Point Sampler Ambient Monitor increases from 0.90 to 0.97. With furthur increases in path length, the sensitivity is increased but the possibility of intercepting additional plumes is increased and at 930 metres the correlation coefficient against the PSAM is 0.95 for one four hour period and below 0.6 for a second four hour period. However, by discarding the data contained in one half-hour period, the correlation coefficient is increased to 0.91. For a path length of 930m, the Long Path Ambient Monitor is thus more representative of an area than the Point Sampler.

Correlation between the PSAM and the Coulometric analyser was excellent at 0.987. Corration between the correlation instruments and the wet chemical tests averaged 0.85 while correlation between the coulometric analyser and the wet chemical method fell to 0.80 due in past to the distance between the coulometric and the wet chemical sampling which was carried out in the PSAM trailer.

5.7 CONCLUSION

It is concluded that the Long Path and Point Source Ambient Monitors gives a reliable estimate of the SO_2 concentration but that the Long Path configuration using a 1000m path length can give poor correlation with the Point Sampler results. While the PSAM measures the concentration at a point, the Long Path Monitor gives a better indication of gas concentrations in a given area.

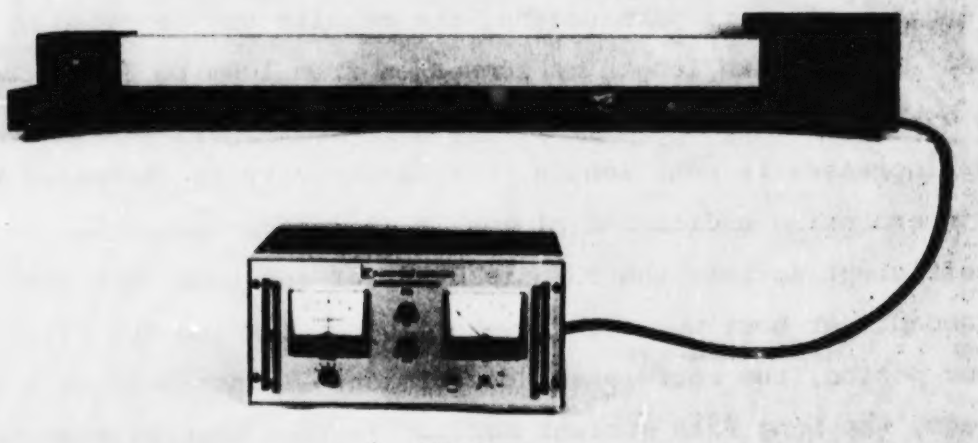


FIG. 5 -1.

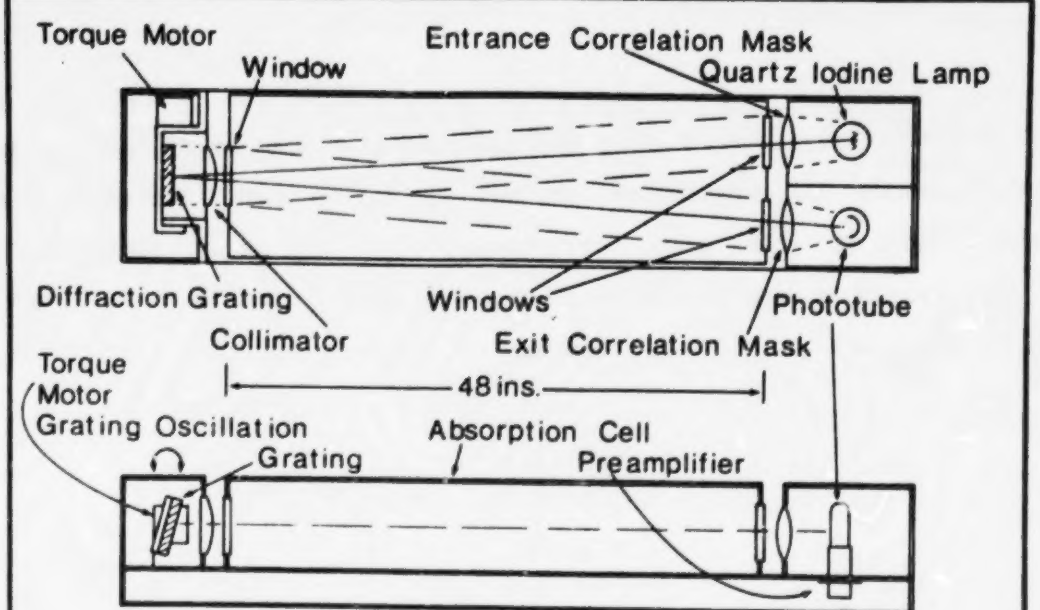
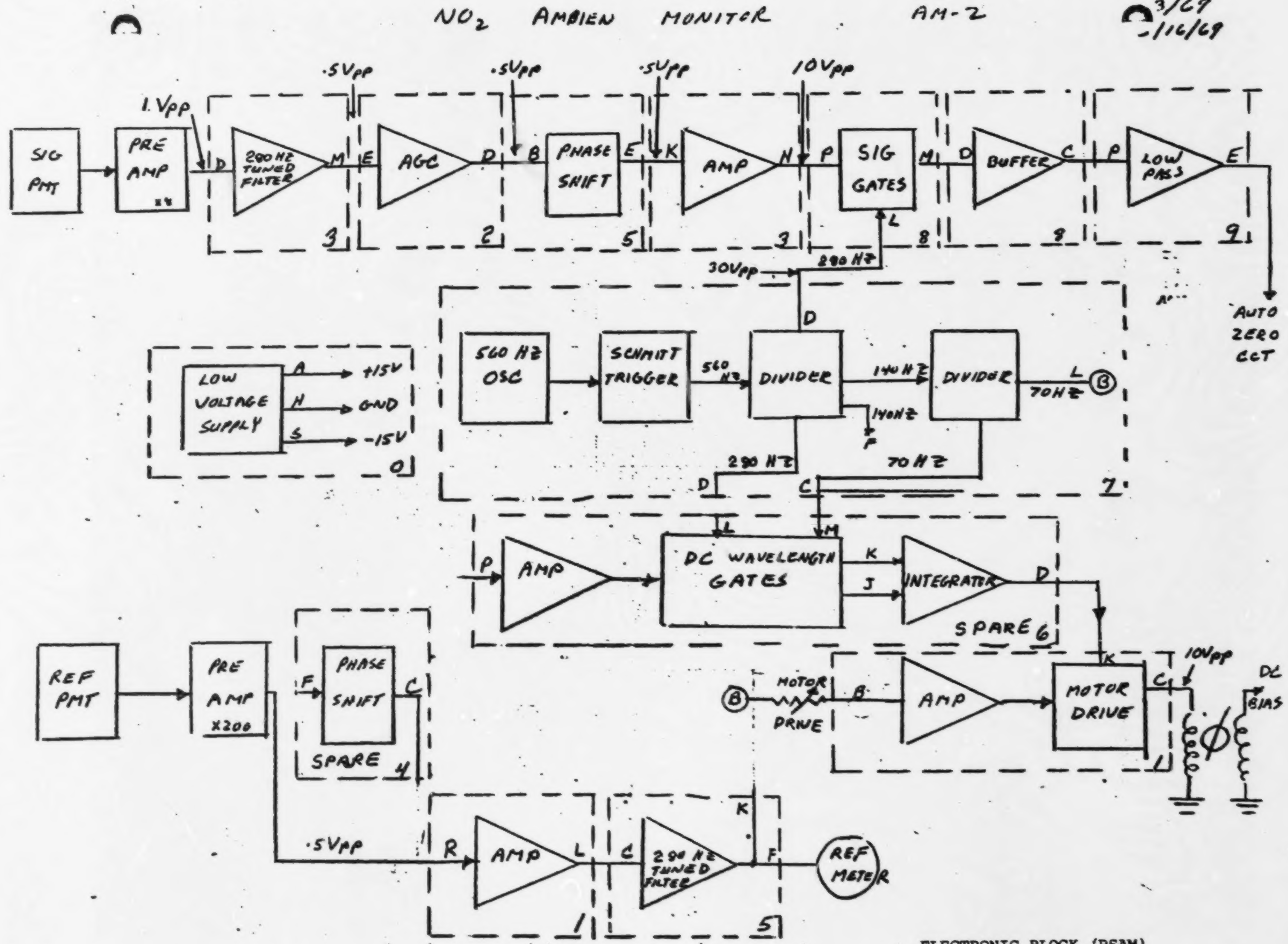

Torque Motor
Window
Entrance Correlation Mask
Quartz Iodine Lamp
Diffraction Grating
Collimator
Windows
Exit Correlation Mask
Phototube
48 ins.
Torque Motor
Grating Oscillation
Grating
Absorption Cell
Preamplifier

FIG. 5-2.
SO_2 AMBIENT MONITOR SCHEMATIC


NO₂ AMBIEN MONITOR AM-2
3/69
-/16/69
SIG PMT
PRE AMP
1. Vpp
280 HZ TUNED FILTER
.5Vpp
AGC
.5Vpp
PHASE SHIFT
.5Vpp
AMP
10Vpp
SIG GATES
BUFFER
LOW PASS
AUTO ZERO CCT
30Vpp
280 HZ
LOW VOLTAGE SUPPLY
+15V
GND
-15V
560 HZ OSC
SCHMITT TRIGGER
560 HZ
DIVIDER
140 HZ
DIVIDER
70 HZ
140 HZ
280 HZ
70 HZ
AMP
DC WAVELENGTH GATES
INTEGRATOR
SPARE 6
REF PMT
PRE AMP X200
PHASE SHIFT
SPARE 4
MOTOR DRIVE
AMP
MOTOR DRIVE
10Vpp
DC BIAS
.5Vpp
AMP
280 HZ TUNED FILTER
REF METER

ELECTRONIC BLOCK (PSAM)

FIGURE 5.3

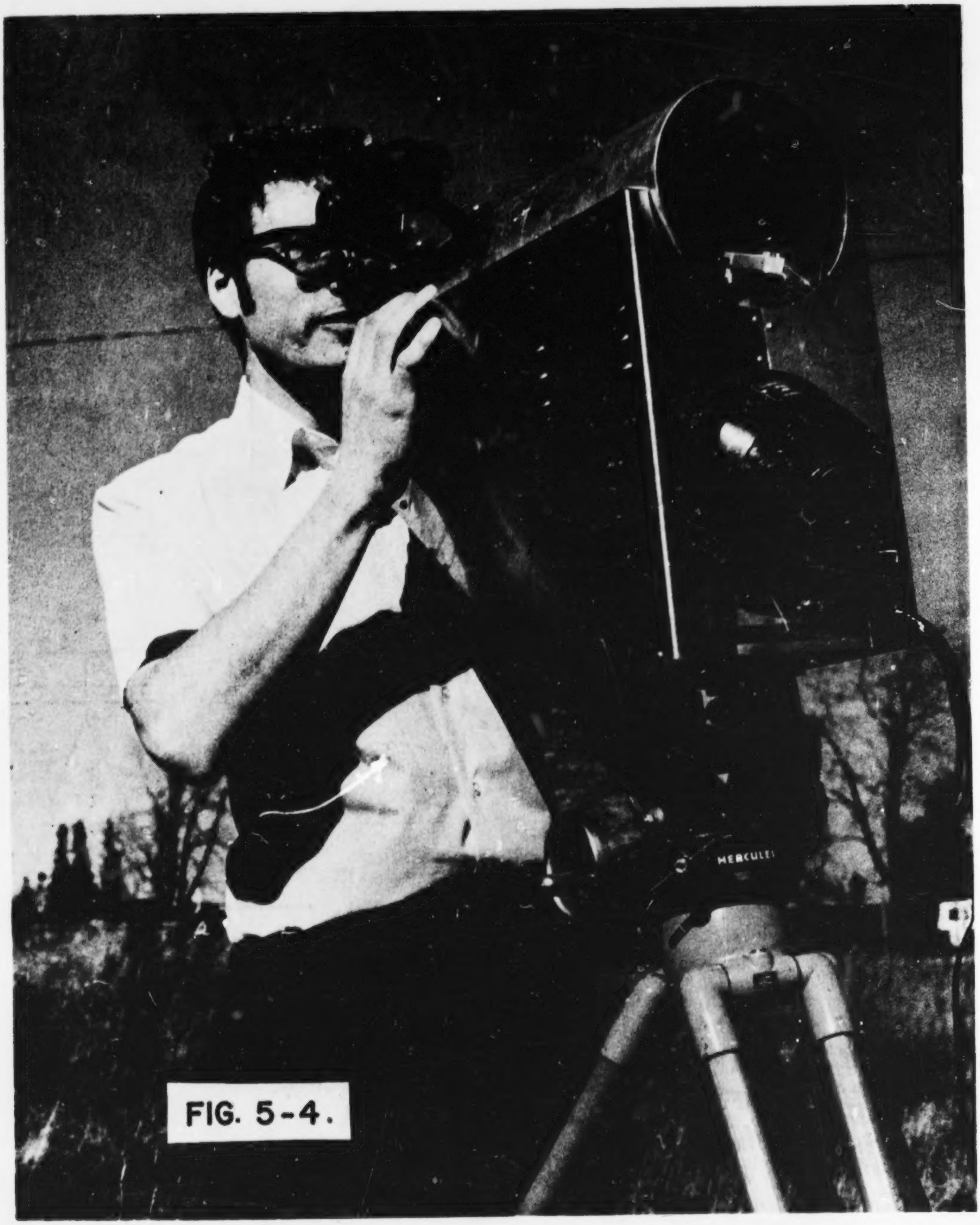
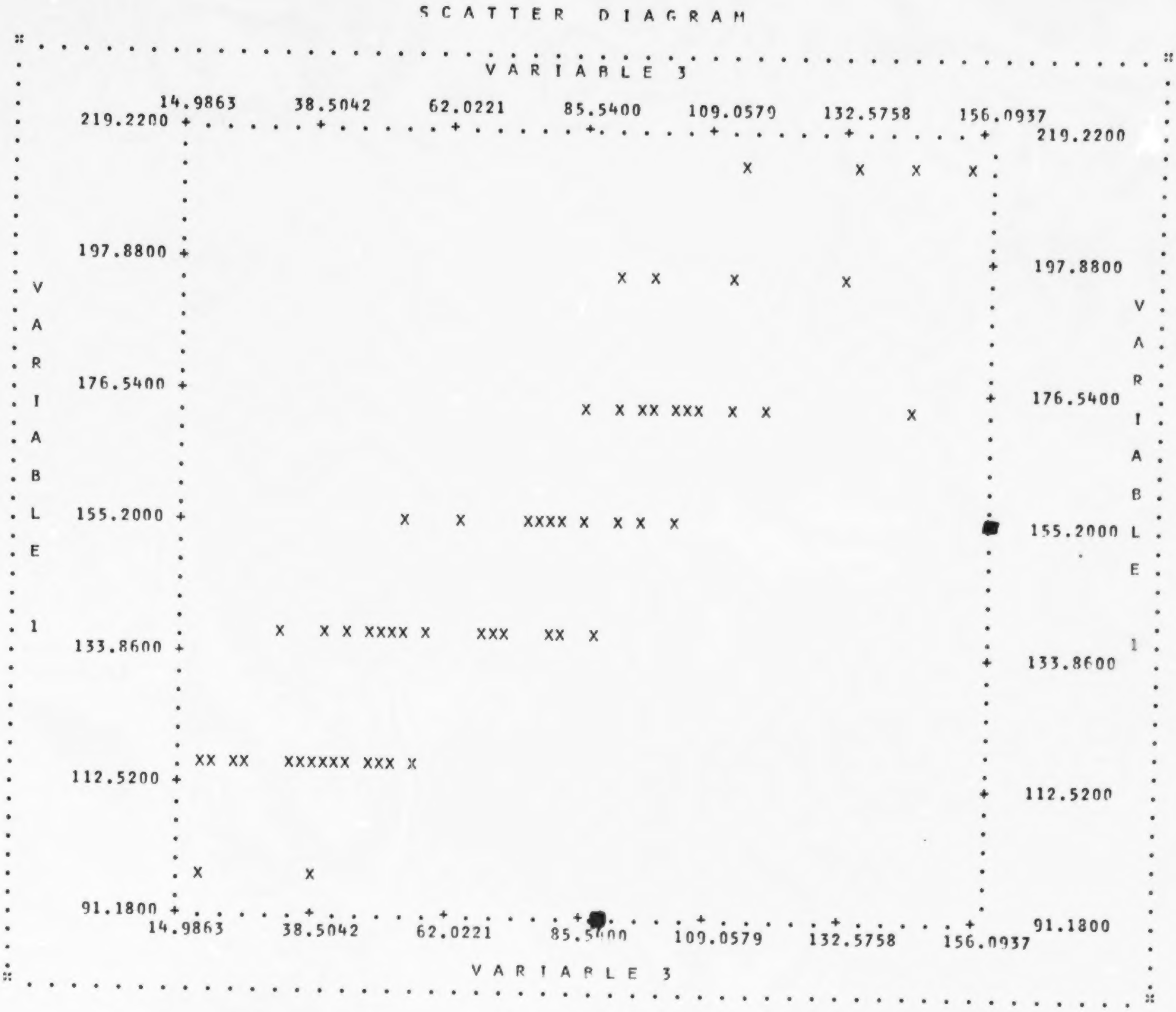
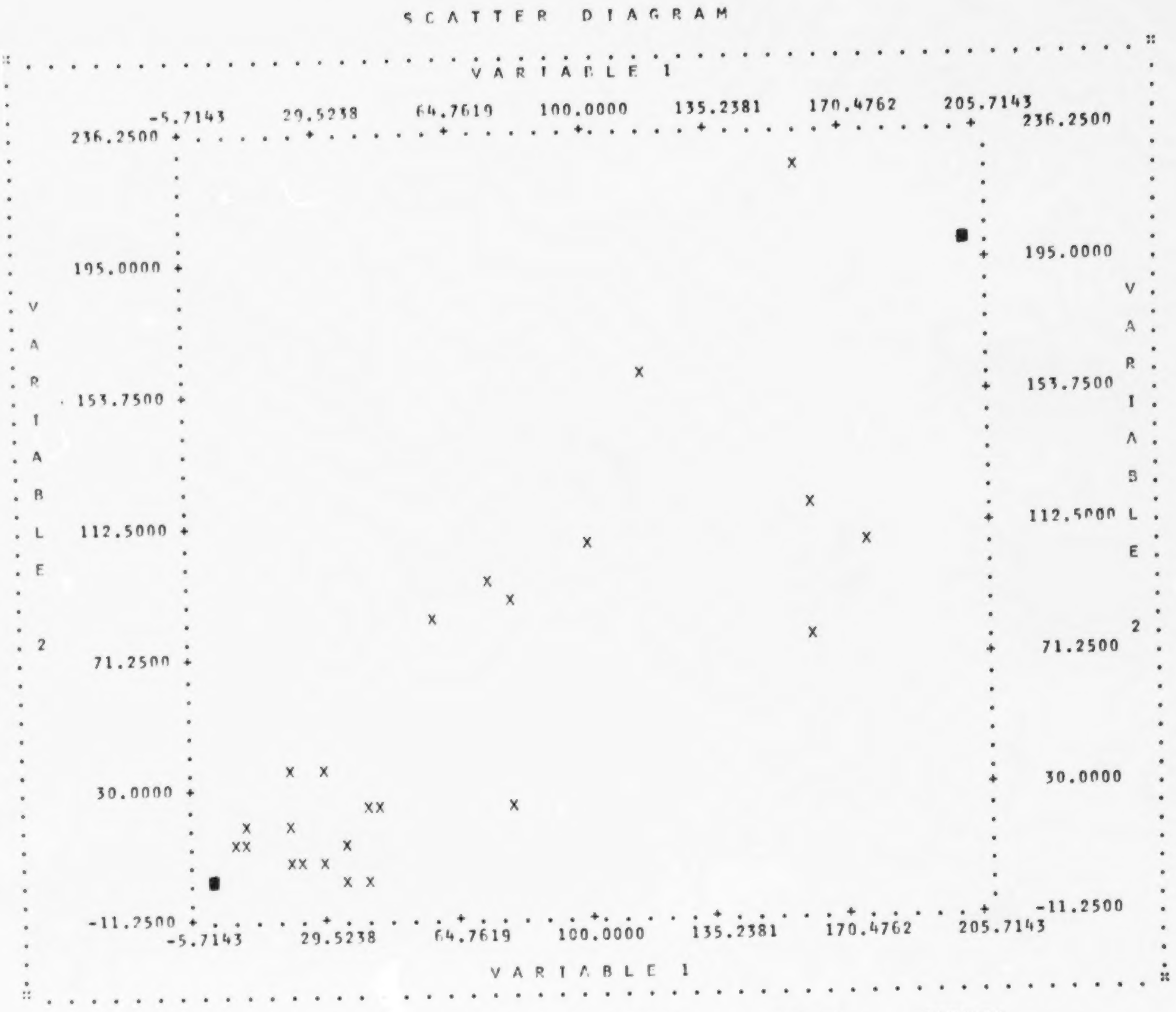


FIG. 5-4.



```
                          INTERVAL SPACING        MINIMUM        MAXIMUM
SCALING FOR VARIABLE  3  ---      3.919651         18.8000       152.2800
SCALING FOR VARIABLE  1  ---      3.048571         97.0000       213.4000
```

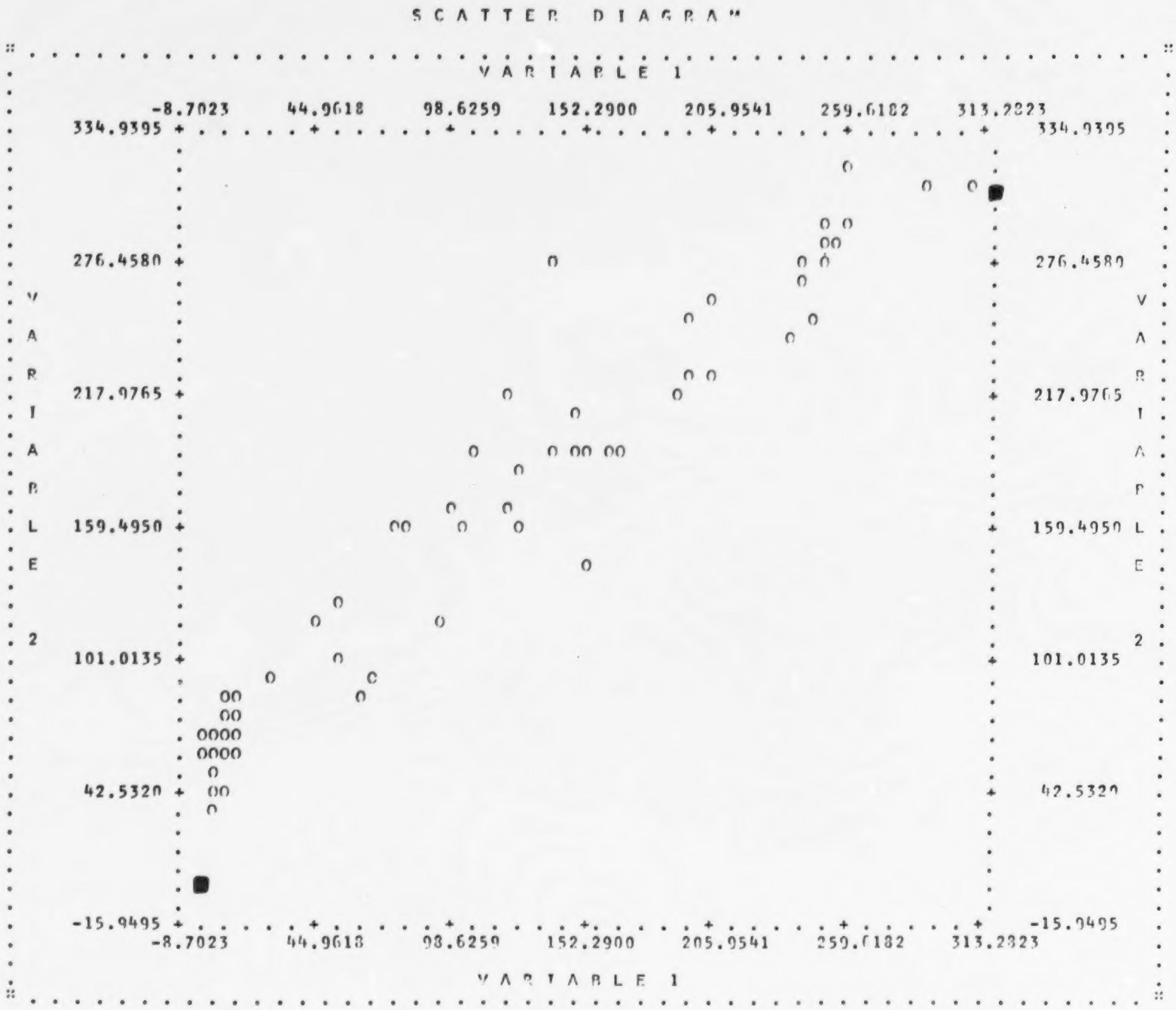
FIGURE 5.5



```
                                  INTERVAL SPACING       MINIMUM       MAXIMUM
SCALING FOR VARIABLE  1  ---          5.873016             0.          200.0000
SCALING FOR VARIABLE  2  ---          5.892857             0.          225.0000
```

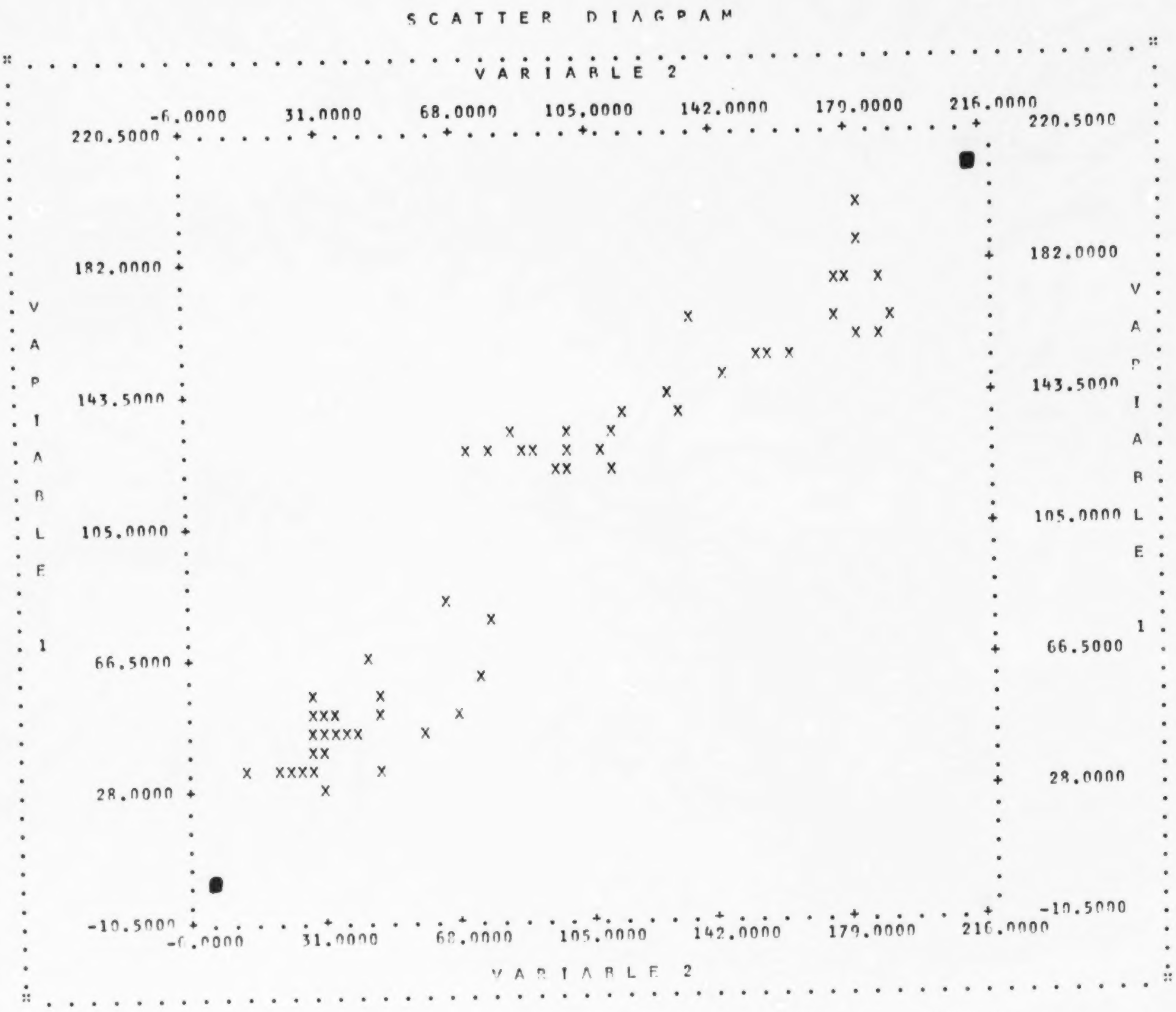
FIGURE 5.6

6



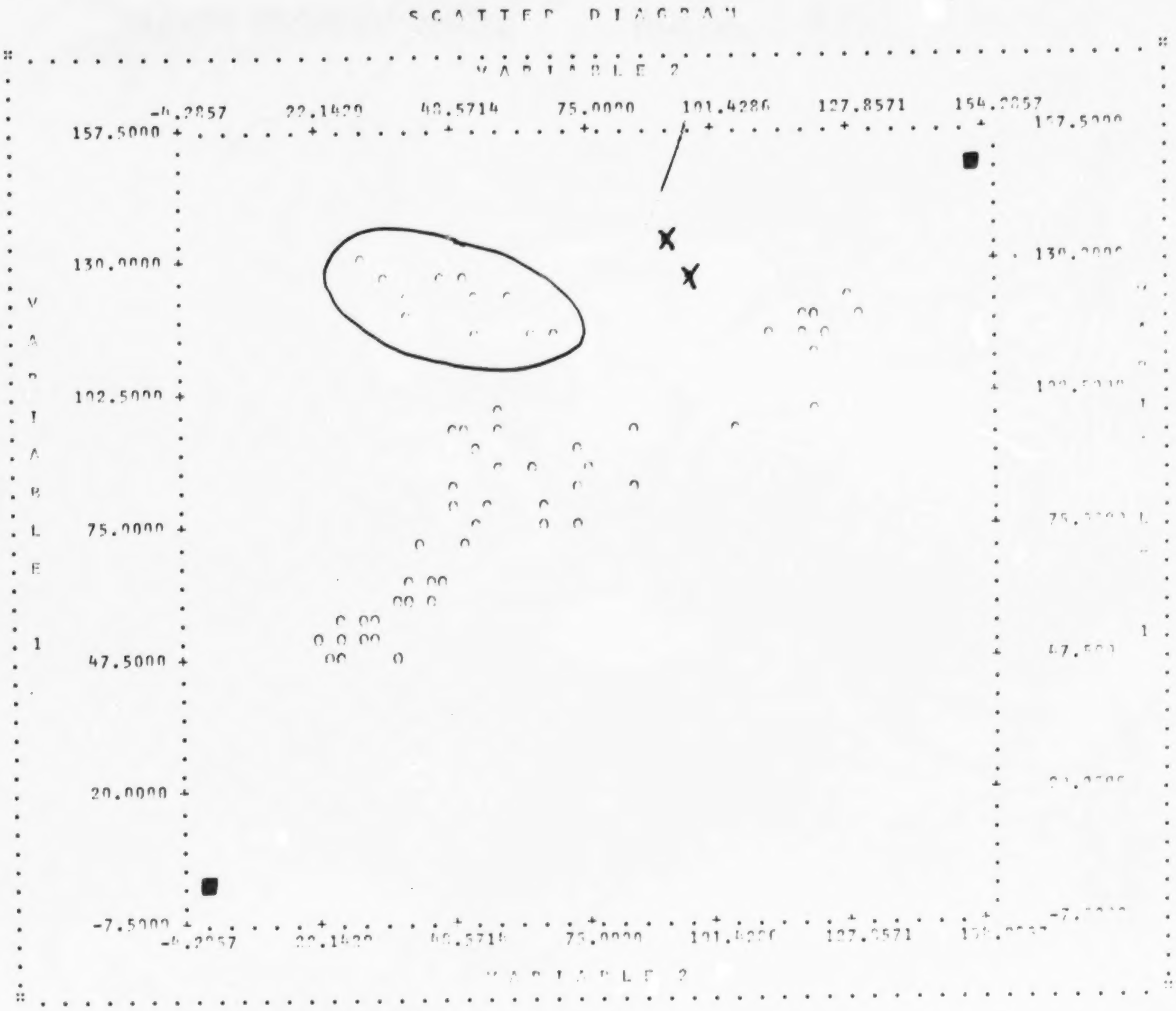
```
                                     INTERVAL SPACING        MINIMUM        MAXIMUM
SCALING FOR VARIABLE  1  ---             8.944016              0.          304.5800
SCALING FOR VARIABLE  2  ---             8.354500             -0.          318.9900
```

FIGURE 5.7



```
                              INTERVAL SPACING        MINIMUM         MAXIMUM
SCALING FOR VARIABLE  2  ---       6.166667             0.             210.0000
SCALING FOR VARIABLE  1  ---       5.500000             0.             210.0000
```

FIGURE 5.8

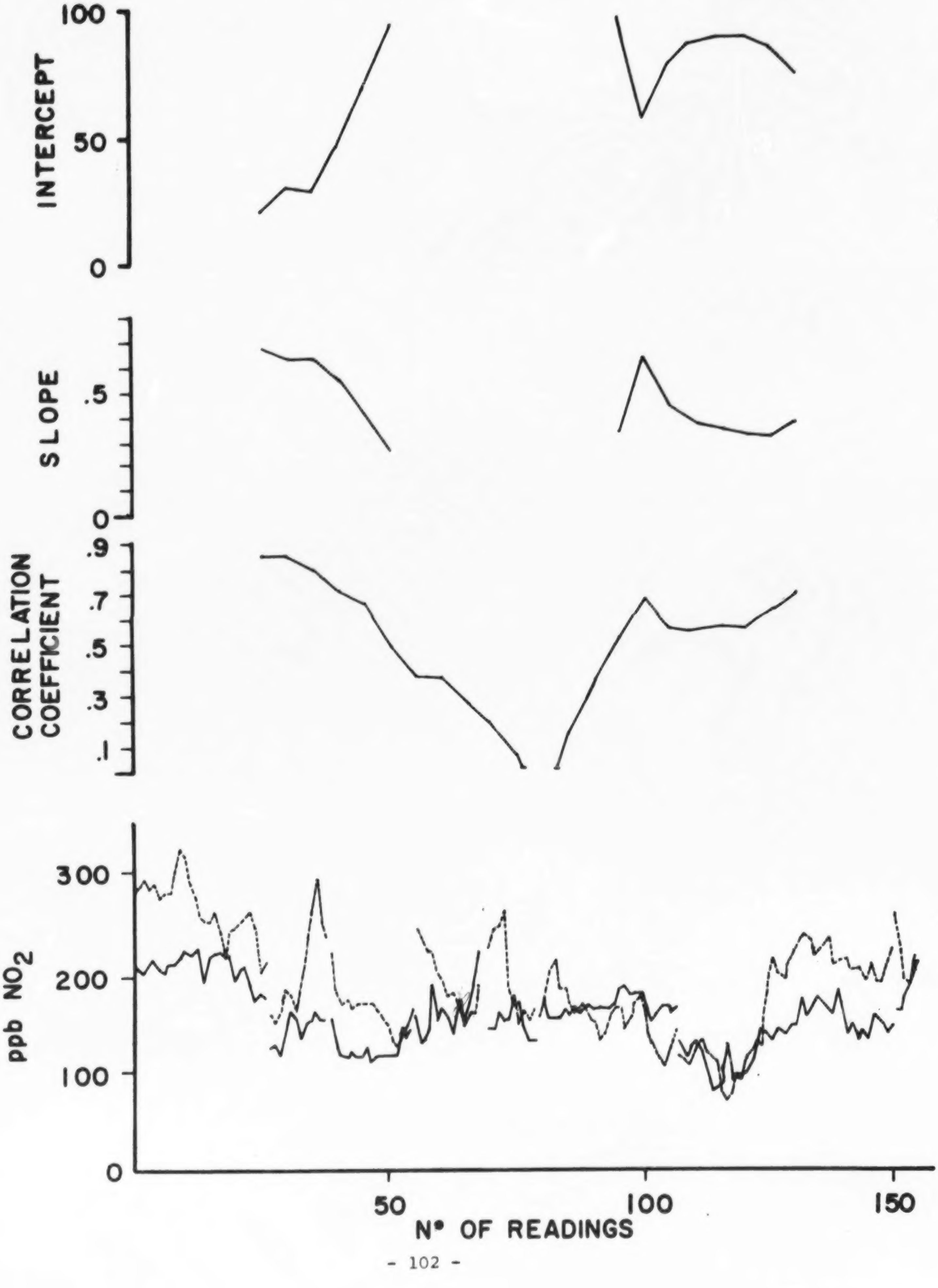


```
                              INTERVAL SPACING        MINIMUM         MAXIMUM
SCALING FOR VARIABLE  2  ---      4.404762              0.            150.0000
SCALING FOR VARIABLE  1  ---      3.928571              0.            150.0000
```

FIGURE 5.9

FIGURE 5.10

SLIDING CORRELATION LPAM VERSUS PSAM



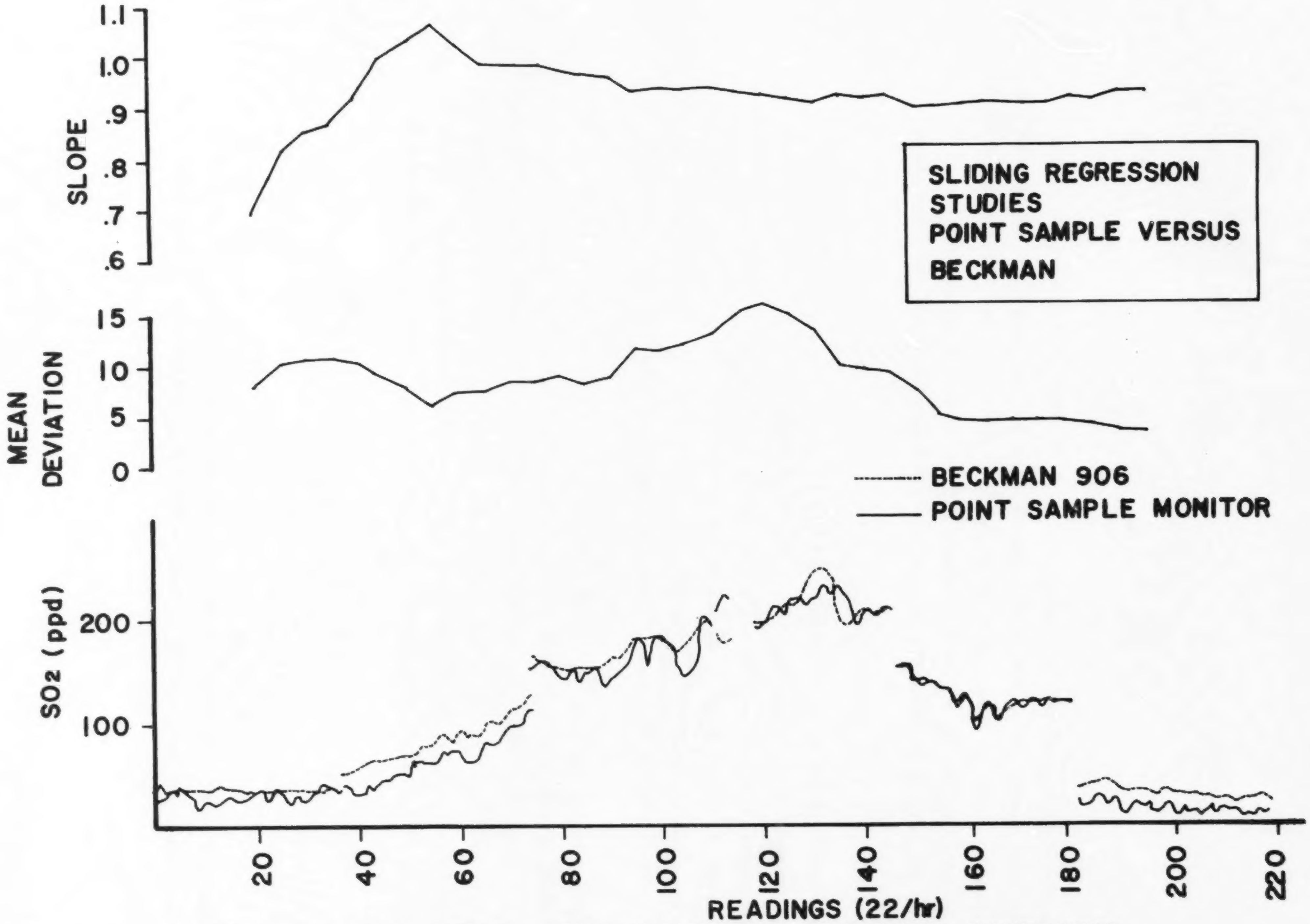


FIGURE 5.11 SLIDING CORRELATION – PSAM VERSUS BECKMAN ANALYSIS

Section 6

PHASE IV

6.1 INTRODUCTION

The broad object of Phase IV was to study the various configurations of the correlation spectrometer for the measurement of NO_2 to give data unobtainable by classical means. These tests were carried out in the Los Angeles basin are of southern California where at certain times during the year high levels of ambient NO_2 can be confidently expected. The tests were divided into three parts:

(a) measurement in an average urban location
(b) comparison of measurements on and off a freeway
(c) repeated passes by the airborne spectrometer along a wind trajectory to demonstrate the movement of the NO_2 peak inland during the morning and outwards during the afternoon and the influence of land-sea breeze.

The quantity and nature of the equipment needed for these tests indicated that packing and shipping by normal carriers would involve a considerable amount of work. Consequently the necessary benches and facilities were constructed in an air conditioned truck, which carried the electronics, the recorder, and the water bath containing the permeation tubes for calibration purposes. The point sample ambient monitor was mounted under a bench suspended on elastic cords.

6.2 PHASE IV (A) OBJECTIVE

The objective of the Phase IV (A) experiments were to repeat the comparison between the long path and point sample ambient monitors (as in Phase III) for measurements of nitrogen dioxide in a photochemical pollutant environment. Simultaneously with the ground work addition airborne measurements were to be made at various altitudes, directly over the ground test location. In this manner, studies could be made of both the horizontal and the vertical variations in the NO_2 concentration.

6.3 LOCATION

During a preliminary visit, Brackett Field was selected for the test site because:

(1) The airport offered good facilities for flying and for ground support of the aircraft.
(2) The aircraft and flight team when grounded, were available for other duties.
(3) The airport approach patterns enabled the aircraft to fly over the monitors at low levels.
(4) The airport markings and radio control helped the pilot to locate and overfly the monitors.
(5) There are few open spaces where 4000 ft. line of sight survey can be set up in the Los Angeles area.

Brackett Field is located north of the San Bernadino Freeway at Pomona and about 4 miles from an APC District monitoring laboratory in northern Pomona The runway is in excess of 4000 ft. and is marked by a Lake at the western end and the open expanse of the Los Angeles Fair Ground at the eastern end.

6.4 INSTRUMENTATION

The point sample and long path ambient monitors used for the Phase III tests were converted to NO_2 operation, for the field work at Brackett Field, California. Fortuitously, the local District maintains a monitoring laboratory in North Pomona that has a Beckman NO/NO_2 colorimetric analyzer based on the Saltzmann reaction. In this instrument the air stream is reacted with Saltzmanns reagent to remote the NO_2, then bubbled through potassium permanganate solution to convert the NO to NO_2 followed by a further treatment with Saltzmann's reagent.

6.5 EXPERIMENTAL PROCEDURE

The point sampler, installed in the truck and located at the base of the control tower was run continuously. (Figure 6.1). The instrument showed considerable sensitivity to ambient temperature and inspite of the efforts of the air conditioner, the temperature in the body of the truck sitting unshaded in the California sun showed diurnal variations of 25°F. The zeroing circuit functioned satisfactorily and automatically re-established the zero at 2 hourly intervals. However, under the worst temperature fluctuations, considerable zero shift was evident during this period, and at times, re-zeroing was carried out hourly. The instrument was subject to dynamic calibration about once a week and initially a static calibration using the standard gas cell was carried out automatically every 2 hours in the re-zeroing cycle. After 10 days, it was established that the calibration was sufficiently stable to permit manual calibration only once per day and the loss of data occuring during the 2 hourly re-zero/calibrate cycle was considerably reduced. Apart from the temperature sensitivity this instrument functioned perfectly throughout the course of the experiment.

The long path ambient monitor was set up on a pathlength of 1400 meters, the point sampler monitor being located half-way along the path and just off to one side. The system operated in a satisfactory manner; no problems were found in the two areas of greatest concern, namely maintaining the alignment of the sensor on the light source and spurious signals from fluctuation in the power voltage and frequency derived from a 6Kw motor generator set. The only source of interference was found to be the breakthrough of sunlight in spite of the instrument's intended rejection of unchopped light. This resulted in high spurious readings when the sun came within a solid angle of about 45° to the optical path, subtended at the instrument.

Wet chemical analyses were carried out manually both at the location of the point sampler and along the optical path of the LPAM. The time interval between determination was variable but almost continuous determinations were carried out over long periods during high gas concentrations. With the LPAM and light source both located at the edge of the taxi strip it was possible to collect integrated samples from a path only a few feet from the light path, care being taken not to interrupting the light path.

The airborne work was conducted out of Brackett Field. Initially some ten days of survey was lost because a mounting in the airborne spectrometer had worked loose. This loss was of no importance since the NO_2 levels were low and seldom exceeded 30 ppb. The operation of the aircraft was severely restricted by the smog, especially during days of high NO_2 readings. Visibility just after daybreak in the vicinity of Pomona varied from less than one mile for high smog days to about 3 miles on low smog days. Take offs and landings are permitted only with visibilities in excess of 2 miles (Special V.F.R. Conditions) and take offs were thus delayed sometimes until just before noon during heavy smog. The intention to follow the buildup of smog from the early morning conditions was therefore abandoned and most flights were confined to the period of 10:30 a.m. to 4:00 p.m.

6.6 RESULTS

We were fortunate to have two periods of high pollution levels during our stay in the Los Angeles area. During the first week only low levels of NO_2 were recorded (below 30 pphm) and the District station also showed low values. However, the district station consistently recorded values 50 to 100% higher than our values and we were promoted to make careful calibration of both our own and the district instruments to establish the reason for the difference in readings. During the second week a series of medium to high smog episodes occured giving rise to NO_2 concentrations over 100 pphm on most days. The third week was characterized by a period of medium to low smog levels followed by medium to high levels during the last week when the other phases of the program were being run.

6.6.1 LAPCD MONITOR

During the first week of our operation only low levels of pollution were recorded but there appeared to be a consistent differences between the Barringer Point Sample Ambient Monitor readings at Brackett Field and the LAPCD readings using the Beckman instrument at the district office. It was decided therefore, to calibrate both instruments against a common wet chemical method. Sample bags of 10 cu. ft. capacity were fabricated by sticking together a number of polyethylene bags using scotch tape. With care, it was possible to make gas tight joints and produce bags which could be inflated by means of a small plastic pump to hold a pressure of 1" water gage for a period of several minutes. The inflated bag was injected with sufficient NO_2 from a gas bottle to yield a calculated concentration of 300-400 ppb. This sample was sufficient to obtain simultaneous readings by both the automatic analyzer and the wet chemical method. Since the point sample ambient monitor had been routinely calibrated against the wet chemical method, no discrepancy was expected or uncovered during this calibration.

The LAPCD analyzer is a Beckman NO_2 colorimetric system based on absorbing the NO_2 in Saltzmann reagent, oxidizing the NO to NO_2 by potassium permanganate and determing the additional NO_2 by further reaction with the reagent. Two calibration runs carried out at 400 ppb showed that the NO_2 reading derived by the Beckman instrument agreed with the wet chemical determination within 4%. It was further noted that the Beckman instrument recorded a nitric oxide concentration of approximately 20 ppb and it was first suspected that this was due to a low efficiency of the NO_2 absorber which allowed unreacted NO_2 to pass over into the NO oxidiser and analyzer. However, the indication disappeared when the permanganate oxidizer was bypassed, confirming the presence of approximately 7% of NO in the NO_2 bottle. These calibration tests showed that the Beckman instrument agrees with the wet chemical method to within 5%.

Consequently, since both instruments agreed with the wet chemical method to within acceptable limits, it is reasonable to assume that these differences were real and caused by true differences between the two locations.

6.6.2 Point Sample Ambient Monitor

Apart from the sensitivity to ambient temperature changes, the PSAM functioned well. The sensitivity (span control) proved to be free from drift so that a manual check once a day was sufficient. The wide fluctuations in temperature in the truck caused the base line to drift as much as 20% full scale deflection in two hours, and since the drift is linear, base line errors of an appreciable size are possible. A section of the chart with a relatively stable baseline is shown in Figure 6.2 and illustrates the short-term variation in concentration. This instrument has a time constant of less than two minutes and gives considerably more information of short-term concentration fluctuations than the Beckman instrument with a time constant exceeding 20 minutes.

6.6.3 Long Path Ambient Monitor

Figure 6.3 is a typical chart for a period of high NO_2 and shows the double deflection on either side of the undetermined zero caused by the slow scan of the grating through correlation to anti-correlation. The actual gas concentration is proportioned to one half the difference between the maximum and minimum values.

This slow sweep has the effect of creating a series of discrete determinations at about two minute intervals in spite of the very fast time constant of the instrument. Fig. 6.4 shows for comparison, a period of very low NO_2. Figure 6.5 shows the trace during a period of breakthrough of sunlight. Under these conditions, output voltages in excess of 10 volts and resenting concentrations in excess of 100 ppm have been recorded. Since the direct sunlight does not enter the field of view of the instrument, the light is presumably directed into the entrance slit by forward scattering. The effect however, is unlike that of dilution discussed in connection with the use of the remote sensor for stack measurements. In that case, the total light flux is enhanced, but the amount of correlation is changed to a lesser extent (if at all) and a lower percentage of correlation is recorded. In the case of sunlight breakthrough, enhanced correlation apparently takes place. It is well established that forward scattered light is strongly plane polarized and consideration is being given to the use of polarizing filters to further discriminate against natural light.

6.6.4 Airborne Instrument

The object of the airborne determinations was to determine the variations in NO_2 burden along a flight line over the airport landing strip and hence over the ground based instruments. Repeated flights were planned in order to study the change in vertical burden with time. Both upward and downward looking measurements were made, as the aircraft altitude was decreased so that vertical sections of the atmosphere were in effect analyzed. These flights, numbers 10, 11 & 12 of July 3rd, 4th and 7th were selected for detailed examination.

6.6.4.1 Flight 10

Figure 6.6 shows a composite of the runs of Flight 10, carried out on July 3rd under conditions of moderate smog. Runs were made at 5,5000 , 3,500 and 2,500 ft. altitudes. Figure 6.6 shows that there is a variation in vertical burden along the flight line; examination of successive runs shows no evidence that the pattern in repeated either in relation to the ground or to the wind. Table B.1

in Appendix B shows the details of the runs and the most important conclusion is the scatter in the readings obtained for upward and downward measurements.

In the case of the upward-looking measurements, it can be assumed that for every photon scattered out of the field of view of the telescope, another photon is scattered into the field of view and that the average pathlength through the target gas is substantially unaffected. The upward looking mode is therefore less sensitive to scatter than the downward looking mode. The data contained in Table B.1 allows the vertical profile to be estimated both from the up-looking modes and it is obvious that the downward looking mode suffers most from scatter. Thus, at an altitude of 1500 ft. (curve 9), the vertical burden is 140 ppm-m. Assuming a 'm' value of 2.4, the indicated levels are 58 ppm-m or an average of 38 pphm. The values for downward observations from high altitudes are less than this value in spite of the additional gas indicated by the 40 ppm-m recorded in the upward looking mode at the lower altitude.

6.6.4.2 Flight 11

Figure 6.7 is a composite for the runs of flight 11 carried out on June 4/69. Of the twelve runs completed in this flight, 10 were considered to be sufficiently defined for digitization and computer plotting. The details of these 10 flights at altitudes of 2000 to 6000 ft. above mean sea level are detailed in Tables B.2 and Table B.3 summarizes the average values for the various traverses. In Table B.3, columns 2 and 3 shows the downward and upward looking values at various heights above the ground. The dilution of the signal by scatter is immediately obvious from column 2, in which the downward integral porgressively decreases as the height of the aircraft increases. Column 3 shows that the gas recorded by the upward looking sensor at least increases progressively as the amount of gas above the aircraft increased. Column 4 shows the difference between the upward and downward mode and indicates that within the limits of experimental error, the net downward value is constant irrespective of height. It must be assumed therefore, that the spectrometer in the downward looking mode sees virtually no light reflected from the ground but records only a signal scattered back from below the aircraft.

Since the scattered signal is constant down to 1000 ft. above the ground, the majority of the back scatter originates from a region not more than 1000 ft. below the aircraft.

6.6.4.3 Flight 12

Run 12 was carried out on July 7/69 from 4:20 to 5:30 pm, a day of moderate smog which is confirmed by the profiles which suffer less back scatter than those in run 11. Six runs were carried out at 6500 ft. and 4 runs at 3000 ft. and a comparison of these repeat runs suggests that the total burden available was undergoing considerable fluctuation. (Figure 6.8) Thus, runs 2, 4, 5 and 6 represent repeated traverses at 6500 ft. looking downwards. The average burden recorded for the 4 runs were 38, 42, 55 and 51 ppm-m respectively. Similarly, there is an increase from 77 to 89 ppm-m average between runs 8 and 9 looking downward at 3000 ft. and a change from 18 to 29 ppm-m for runs 7 and 10 at 3000 ft. looking upward. The values of 30 to 43 ppm-m recorded at 5500 ft. looking downwards maybe contrasted with a value of 25 ppm-m recorded at 5000 ft. during flight 11. Similarly the 18 to 29 ppm-m values for 2000 ft. upward looking maybe contrasted with values of 65 to 75 ppm-m for a similar position during flight 11. Thus, the upward looking mode records lower gas levels, but the downward looking mode records higher gas levels as a result of the lower dilution of the signal by reduced scattering under moderate smog conditions. Tables B.4 and B.5 summarize the average values for the various traverses.

6.6.5 Point Sampler Vs Long Path Sampler

The correlation between the point sampler and the long path sampler has been examined in detail for two seven hour periods during the nights of June 28/29 and June 29/30. These were periods of heavy smog with almost calm conditions under a radiation inversion and being during the hours of darkness, the effect of breakthrough of sunlight or skylight was obviated on the long path monitor. Fig. 6.9 shows direct comparisons of readings from the two instruments and fig. 6.10 shows the result of a sliding correlation carried out for the second period. It will be seen from figure 6.9, that the long path monitor, while following in general the fluctuations of the point sample ambient monitor, is subject to minor fluctuations, indicating that the point sampler reading is not often representative of the average for the whole long path and consequently is even less representative of the readings at other points along the long path. The maximum correlation coefficient is 0.92 but for the majority of the period the correlation coefficient is less than 0.7. Under these conditions, the intercept and the slope which are shown for periods when the correlation coefficient is greater than 0.7 have little meaning. These results are consistent with impressions gained on the site that higher gas concentrations often existed at the west end of the runway than at the control tower or the east end of the runway, and that the point sample values tended to be lower than the long path results. It was also noticed when taking integrated wet chemical samples that significant changes in reagent color took place at the west end of the runway while little change in color was seen during the past of the traverses to the east end of the runway. These indications are confirmed by a comparison of the values for wet chemical tests carried out at various points along the runway and for integrated wet chemical samples.

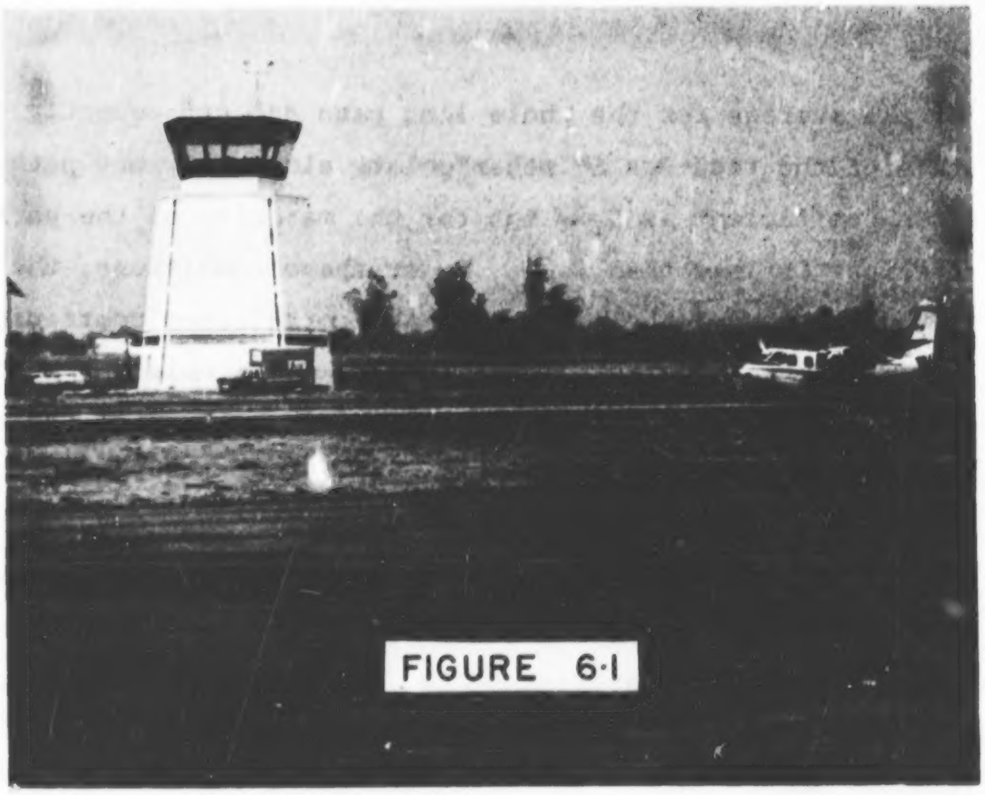


FIGURE 6·1

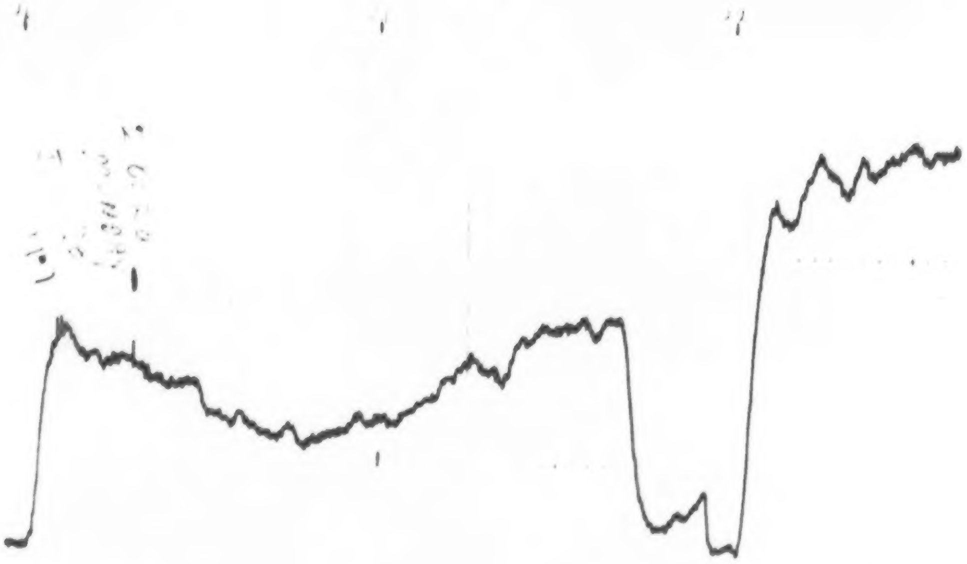


FIGURE 6·2

PSAM CHART 2000 HRS. JUNE 30/69

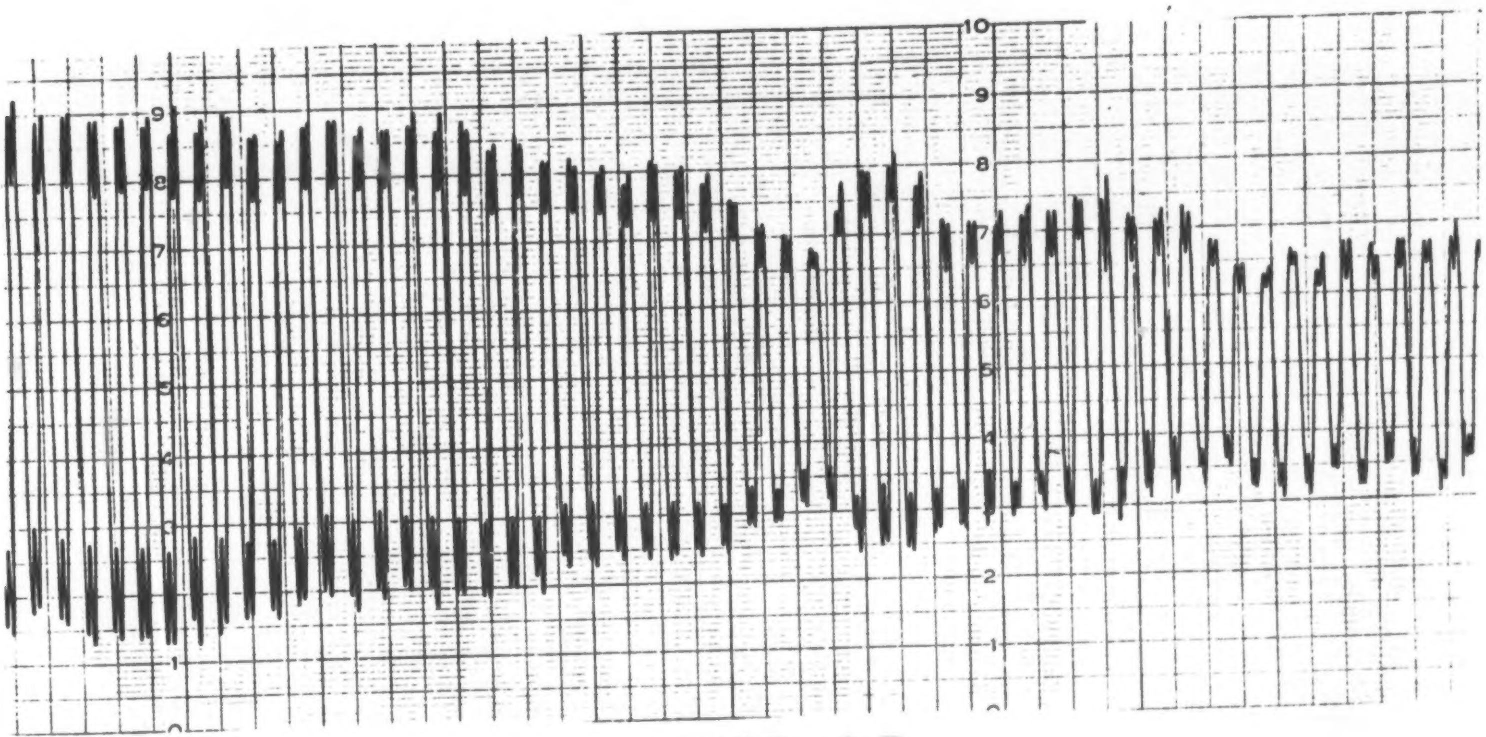


FIGURE 6·3

LONG PATH MONITOR RECORD HIGH GAS

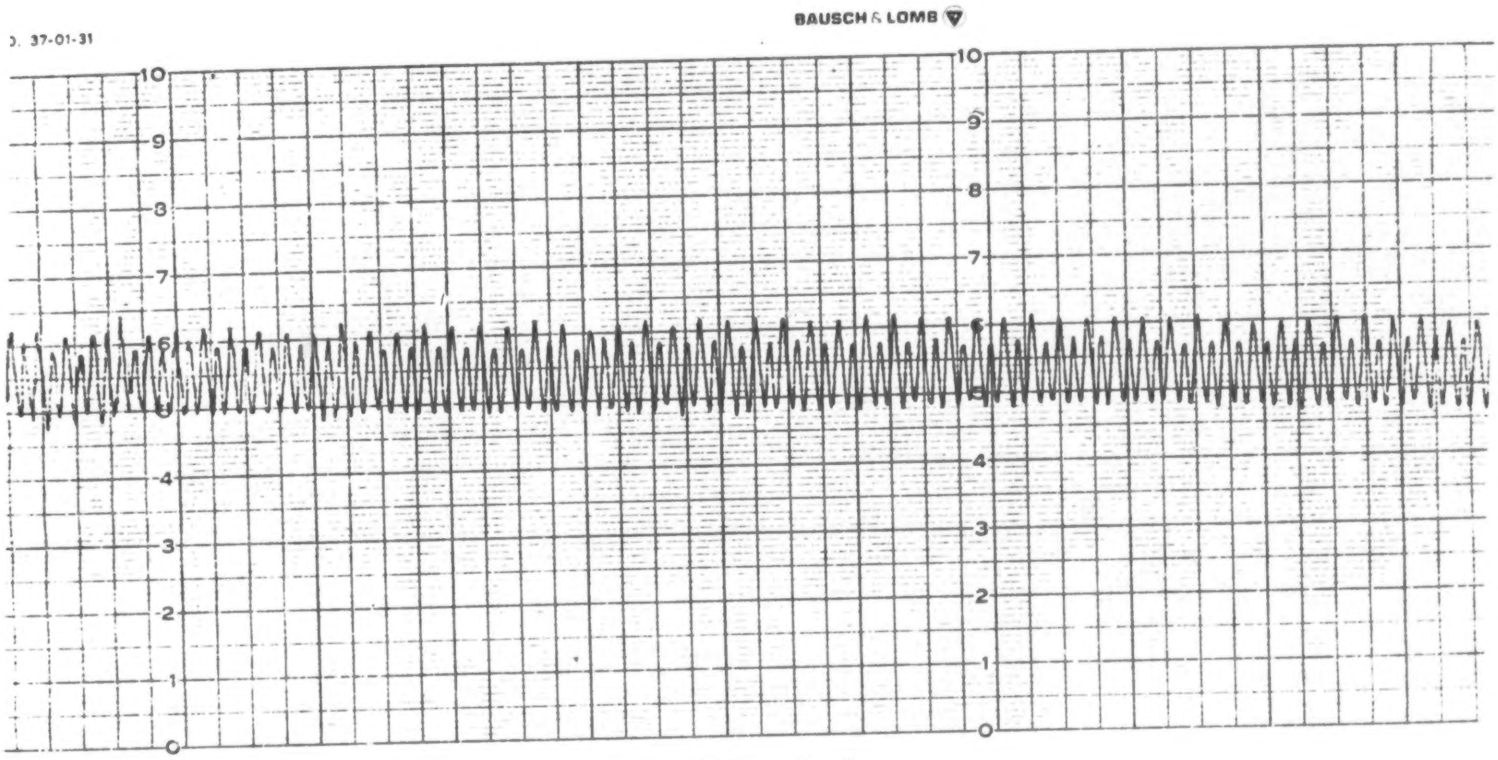


FIGURE 6·4

LONG PATH RECORD LOW GAS

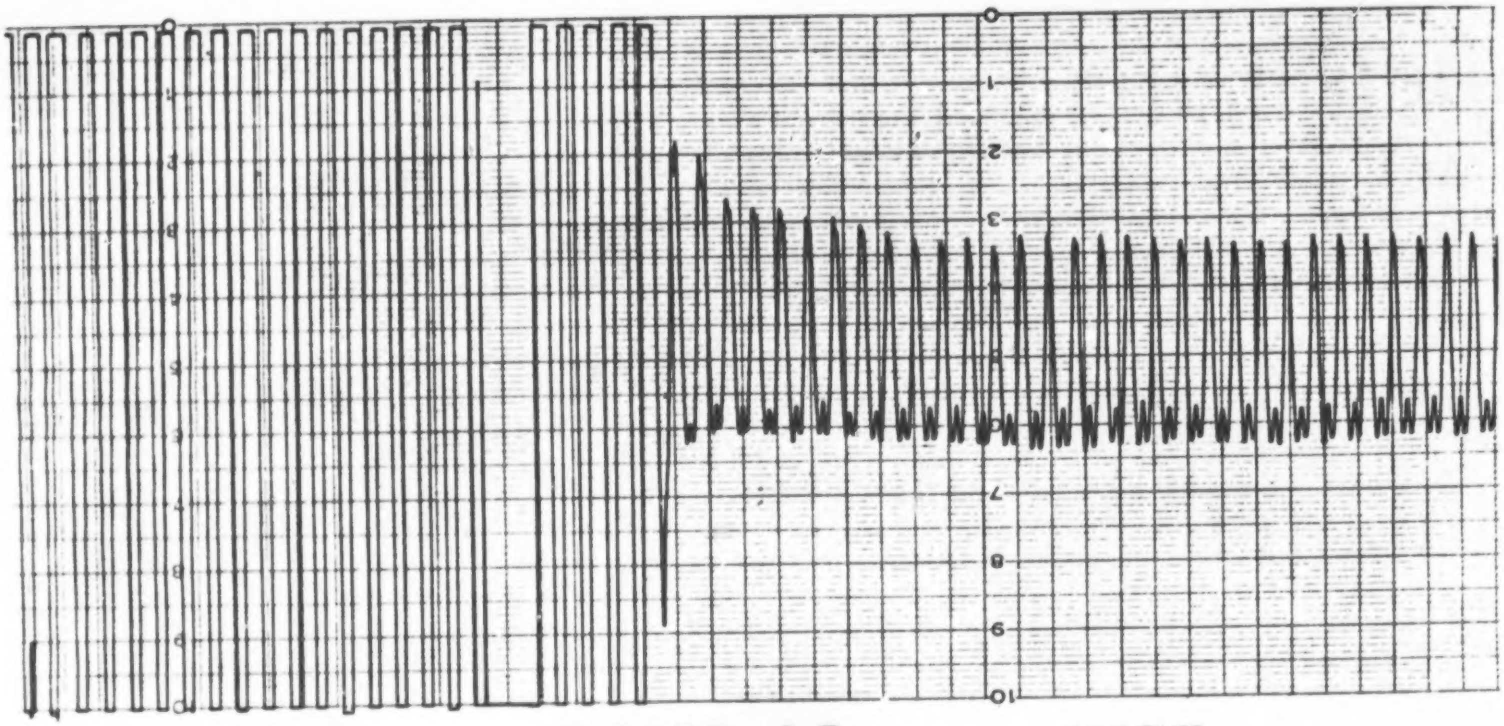


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FIGURE 6·5

LONG PATH MONITOR SUN BREAK-THROUGH

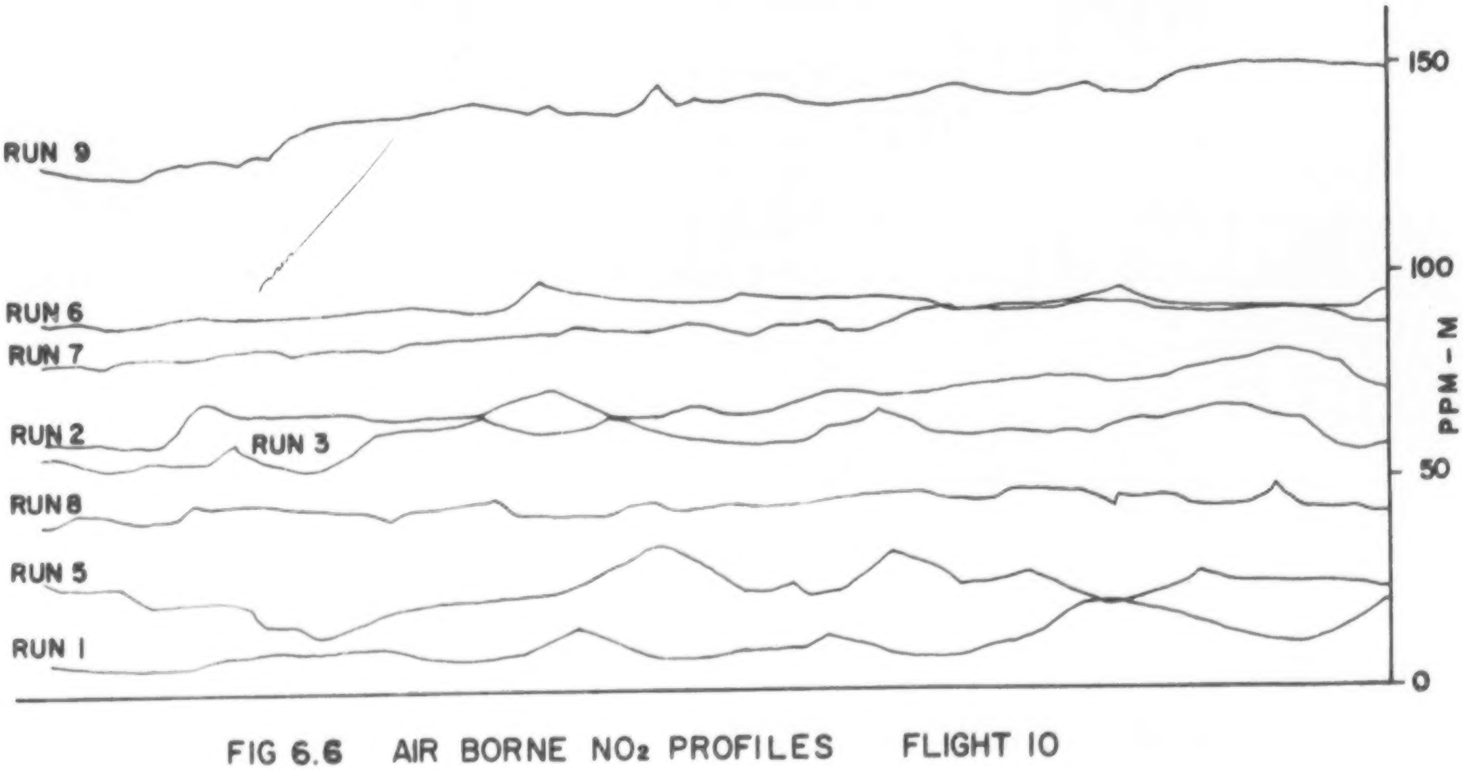


FIG 6.6 AIR BORNE NO_2 PROFILES FLIGHT 10

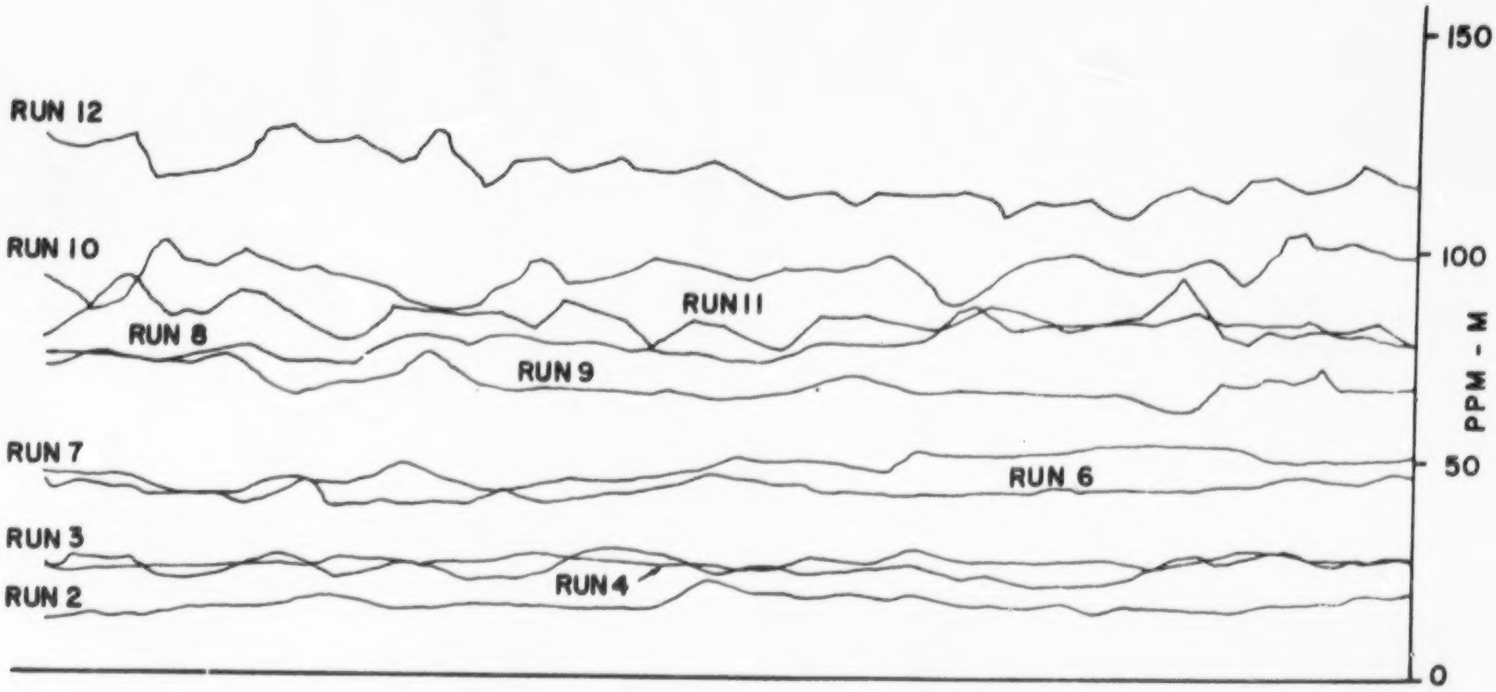


FIG 6.7 AIR BORNE NO₂ PROFILES FLIGHT 11

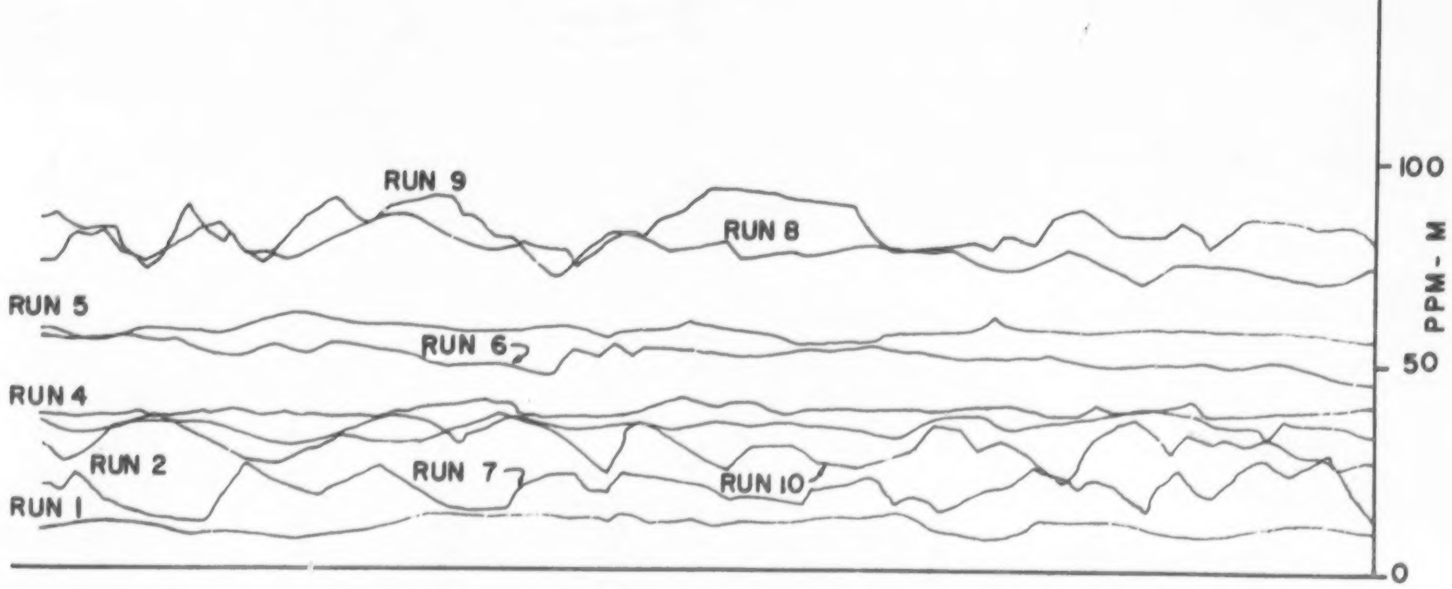
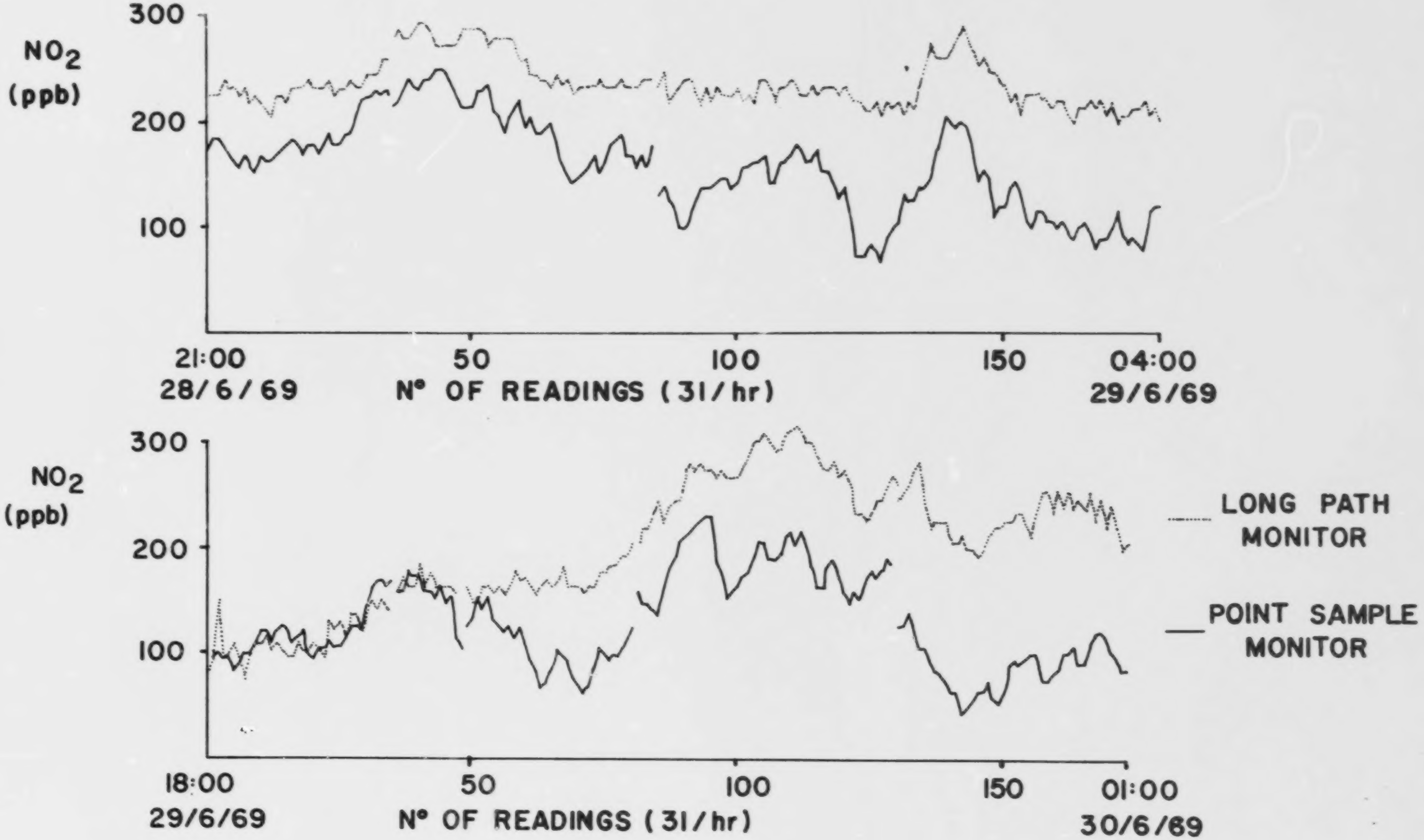


FIG 6.8 AIR BORNE NO₂ PROFILES FLIGHT 12

LPAM VERSUS PSAM

FIG 6.9



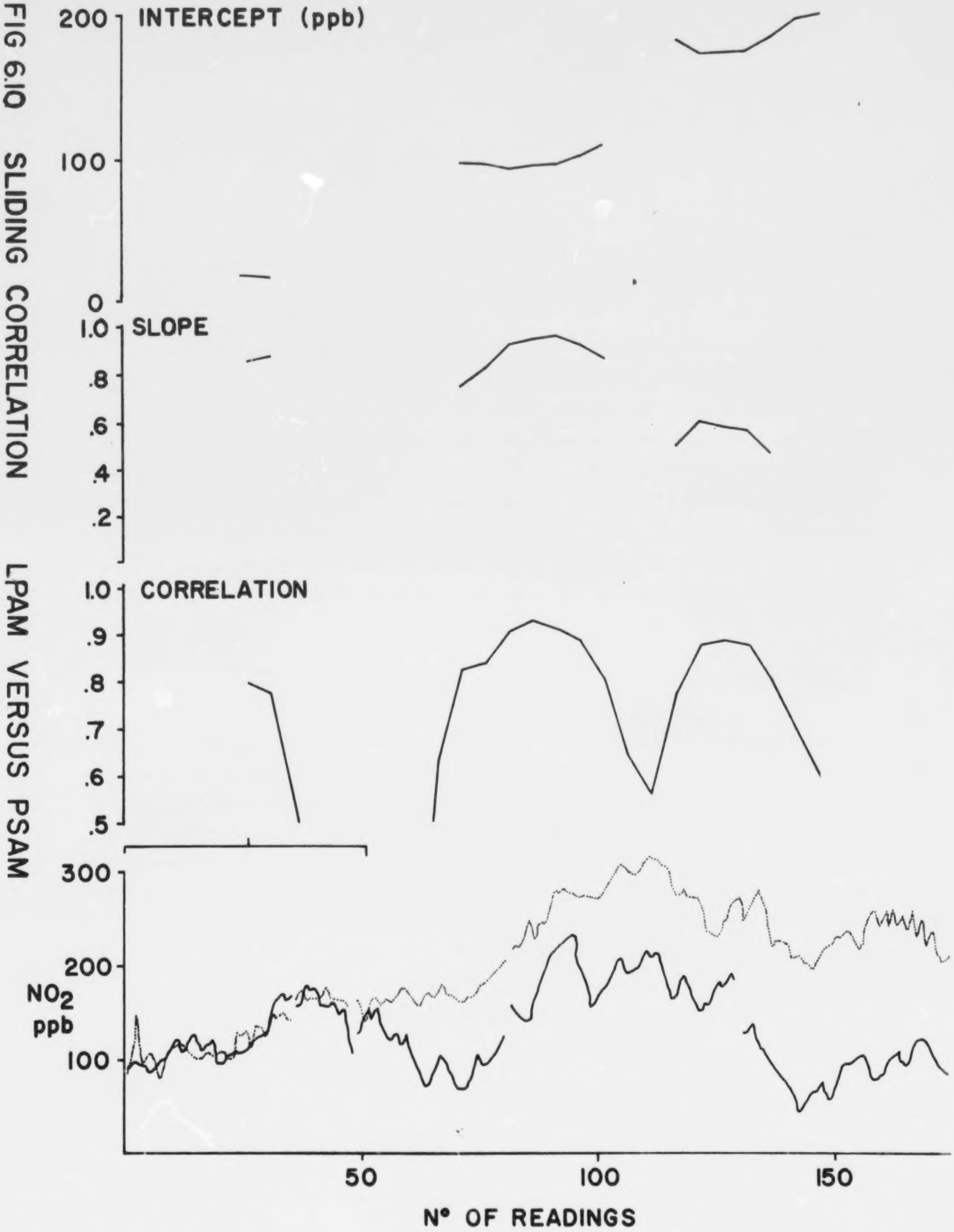


FIG 6.10 SLIDING CORRELATION LPAM VERSUS PSAM

Section 7

PHASE IV B

7.1 OBJECTIVES

The primary objective of this phase of the tests was to compare the concentration of nitrogen dioxide existing on a Freeway with the concentration existing in an area removed from the Freeway traffic. To accomplish this a site was selected where the long path spectrometer could be placed on the shoulder of a Freeway to define optical paths of about one kilometer in length, either along the Freeway to one light source or normal to the Freeway to a second light source. Additional experiments involved the continued operation of the Point Source Ambient Monitor on the shoulder of the Freeway, the collection of both stationary and spatially integrated wet chemical samples along the freeway and traverses across the Freeway by the airborne monitor.

7.2 LOCATION

The site selected was a stretch of the San Bernadino Freeway between Covington and Pomona. The Freeway runs eastward down a hill towards the San Dimas Overpass, curving slightly to the left. The Kellogg Campus of Cal State Polytechnical Institute lies in a valley to the south. With excellent co-operation from the 'Cal-Poly' staff, the spectrometer was set up on the south side of the highway in a lemon grove on the campus. The first light source was set up against the masonry of the San Dimas bridge so that the optical path was approximately tangential to the inside of the curve and made a double pass across all six lanes above the traffic. The second light was set up on a hill on the far side of the Campus overlooking the music department. The spectrometer was set up near a sign board, which hid the activity from traffic approaching on the near side. (The police were perturbed that if the activity was too obtrusive, slowdowns and traffic jams would result).

Figure 7.1 shows the spectrometer located about seven feet off the ground and adjusted to swing horizontally from one lamp to the other. Figure 7.2 shows the approximate location of the optical paths as seen from the San Dimas Overpass. The path length"on the freeway" was 1200 m. and "off the freeway" 900 m.

7.3 INSTRUMENTS

The Long Path monitor was set up on the Campus as described above. The truck housing the Point Source monitor was parked alongside the monitor.

The aircraft continued to operate out of Brackett Field which was only a mile or so north of the Freeway. In fact, the downwind leg of the Brackett landing pattern normally passes over this section of the Freeway and the over flights by the airborne spectrometer had to be adapted and become part of simulated landing circuits.

7.4 EXPERIMENTAL PROCEDURE

In order to compare 'along the Freeway' readings with the 'off the Freeway' readings the long path spectrometer was turned manually from the San Dimas overpass light source to the campus light source at 15 minute intervals. For the first two days this procedure was carried on during daylight hours only and the spectrometer was left unattended looking at the campus light source during the hours of darkness. This was in deference to a promise made to the Freeway Patrol that the San Dimas light source which was situated about 25 feet to the right of the Freeway would not be operated during the hours of darkness. This was made in anticipation that the bright light shining directly into the eyes of drivers of on-coming traffic would create a hazardous situation after dark. Under actual operating conditions the collimation of the light source was better than expected and as these appeared to be no hazard an attempt was made to run the spectrometer looking along the Freeway during the third night. However, complaints from motorists during the night prevented further operation of the San Dimas light during the hours of darkness.

No particular problems were encountered in the wet chemical tests, other than the danger of traversing along the shoulder of the freeway at very slow speed.

Aircraft flights were made whenever visibility conditions permitted. Some interference in flight plans were experienced due to the fact that our flights along the Freeway, especially at 2000 and 3000 feet encroached on the downwind leg of the Brackett Field landing pattern. This was overcome by reporting into the Brackett Field landing pattern and flying a little off course to complete the scan along the Freeway.

In order to extend the analytical data, instantaneous grab samples of 2 cubic foot size were collected in the large plastic bags which were used for the preparation of low concentration calibration samples. By standing on the shoulder of the Freeway, passing traffic was found to create sufficient draft to inflate the plastic bags which were quickly gathered at the neck and sealed. These bags were transported to the truck for analysis by the wet chemical technique. The point sample ambient monitor had a much faster response, so that analyses could be completed quicker with a smaller sample by using the point sample monitor than by using the wet chemical technique. Subsequent analyses of grab samples were all made on the P.S.A.M.

7.5 RESULTS

One of the prime aims of this series of tests was to compare the levels of NO_2 existing over the freeway with values taken to one side. Figure 7.3 shows a plot of the output of the long path ambient monitor for the period from 1100 to 1500 hours on July 9th during which the sensor was alternately sited on and off the freeway. It will be seen that during the period from 1100 to 12:30 hours the value off the freeway was approximately 100 ppb and the value over the freeway 500 ppb. Just after 1300 hours there is evidence of an influx gas which brings the readings to 450 and 750 ppb respectively. This peak coincided with a minor accident which blocked the west bound lane of the freeway for a period of about 15 minutes and resulted in a major portion of the light path passing over stationary traffic, bumper-to-bumper. Around 1400 hours there is evidence of a ventilation with fresh air coming over the freeway and a corresponding drop in NO_2 levels to 400 ppb while the off the freeway values increased to 500 ppb. Figure 7.4 which may be used for an overlay to Figure 7.3 shows the record of the point sample ambient monitor which was located just off the shoulder of the freeway near the long path sensor. There appears to be a slight error of time synchronization and figure 7.4 has been moved so that it can be placed over figure 7.3 to show the close similarity in the various peaks recorded on the point sampler compared with peaks picked up by the long path sampler.

Also shown on figure 7.4 are three wet chemical determinations, 2 stationary samples taken at the truck and one integrated sample on the freeway. The first stationary sample agrees with the long path off the freeway, but it is rather lower than the point sample reading. The second stationary sample agrees with both the point sample and the long path off the freeway reading. The third integrated sample agrees with the point sample but is not in agreement with either of the long path readings unless the long path reading over the freeway which has declined drastically from 1320 to 1420 has continued its drop in spite of the increase in values off the freeway.

Table 7.1 shows the analyses on 11 grab samples taken in 2 cu. ft. plastic bags at various points along the shoulder of the Freeway and on the Cal Poly campus, the first seven values being plotted in figure 7.3. The sample locations are indicated in figure 7.5 together with the optical paths used for the LPAM. Sample II was high and could have been influenced by the proximity of the generator to the "on-freeway" light source, while Sample IV shows build up of gas under a high embankment on the north side of the freeway. The campus samples, taken in two pairs at the library and the Engineering building at 1520 and 1540 hours respectively, show average values of 47 and 95 ppb for the two sample times. The LPAM readings for these times are not directly comparable since the instrument was aligned with the "on the freeway" light source, but were 110 and 250 ppb respectively.

7.5.1 AIRBORNE RESULTS

The airborne results were very disappointing. In the absence of the flight recovery camera, the precise location of the aircraft is unknown and the limitations on aircraft location and maneouvers in the landing circuit distracting the pilots attention probably resulted in some error in navigation which can not now be discovered or allowed for.

Since the Freeway runs along the side of a hill, the actual elevation of the aircraft above the ground changes rapidly even when in level flight. At the same time, the prevailing SW wind carries the gas from the Freeway up against the hill, so that the long optical path length of the airborne monitor when flying over a valley coincides with low gas concentrations, while the shorter path length over the hill corresponds with high gas concentrations. These variables, working inversely to one another, tend to yield a fairly constant and featureless "concentration times path length" parameter from which the location of the aircraft cannot be precisely determined.

Figure 7.6 is an aggregate of a number of runs across the freeway and it is clear that there is no feature which is common even some of the runs, which might be related to known topography and gas sources.

7.6 CONCLUSION

The value of the Long Path Monitor to measure gas concentrations, in inaccessible places, i.e. over busy roads, and to show the differences in gas concentrations recorded over the Freeway and over adjacent areas is clearly demonstrated. The value of the data given here is somewhat degraded by the lack of two sensors and simultaneous measurements. The differences however, are clearly demonstrated.

The variation in the concentrations of the grab samples is large. However, limited comparisons with the long path measurements suggests that the long path average does not necessarily differ significantly from the grab samples which represent a build up of gas against the side of the hill. These high values appeared to correlate, by visual observation, with the passage up the hill of several large diesel trucks in quick succession.

The airborne sensor data yields nothing of value. The absence of the flight recovery data prevents the various flights from being superimposed with confidence. The flight data is devoid of features from which notations of location written on the chart can be verified.

The long path monitor has shown itself useful in measuring average concentrations in inaccessible areas. The data collected shows that during calm conditions the concentration over a freeway may be higher than that over the surrounding area but there is also evidence that with a cross wind, the gas will be blown from the freeway into the neighbouring area. In this particular location, with the 'increasing' elevation of the land coinciding with increasing concentrations of NO_2, and in the absence of flight recovery photography it is impossible to locate the flight path with sufficient confidence to draw any conclusions.

TABLE 7.1

Sample No.	Analytical Method	ppb NO_2
1	Wet Chemical	130
2	PSAM	442
3	"	275
4	"	520
5	"	208
6	"	212
7	"	165
8	"	39
9	"	100
10	"	55
11	"	90

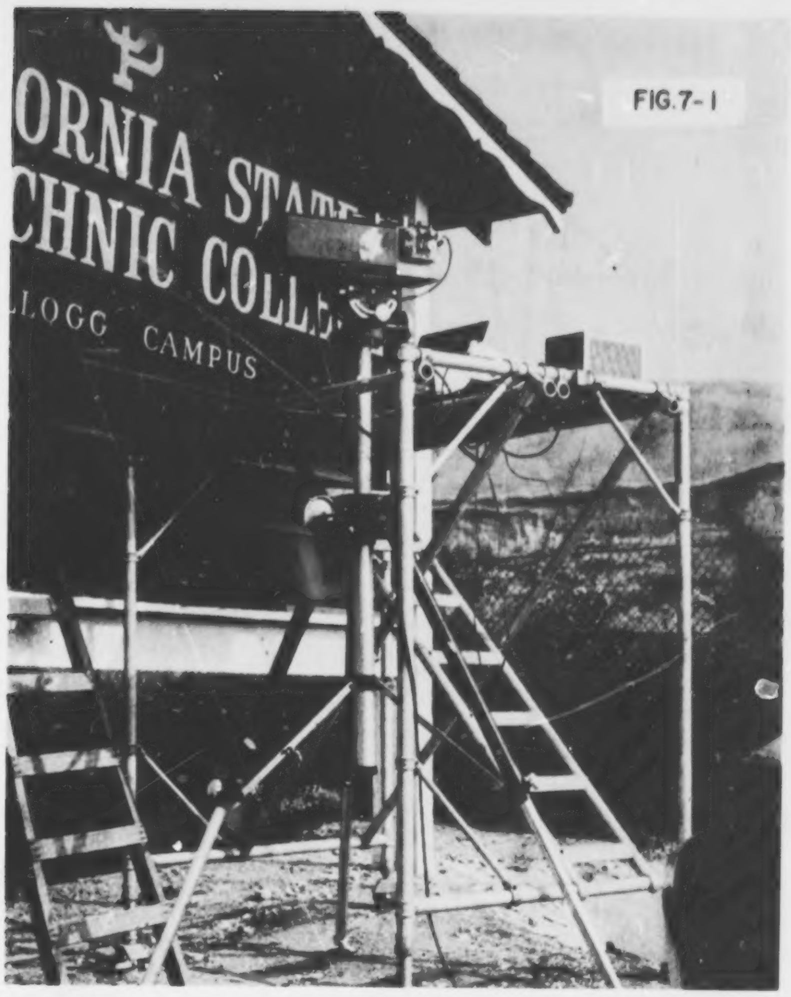

ORNIA STATE
CHNIC COLLE
LOGG CAMPUS

FIG.7-1

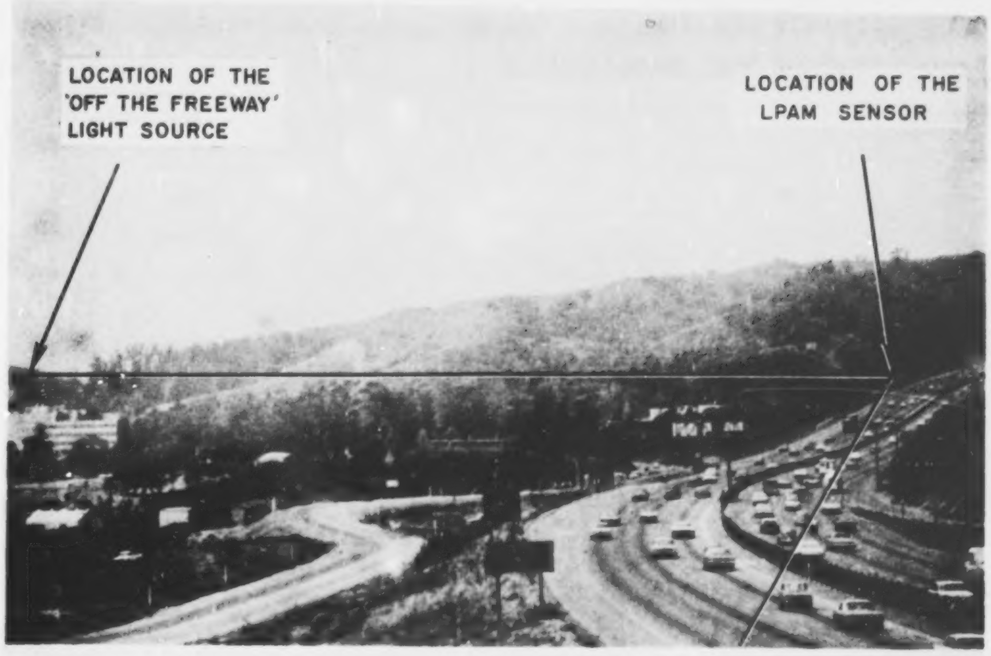

LOCATION OF THE
'OFF THE FREEWAY'
LIGHT SOURCE
LOCATION OF THE
LPAM SENSOR

FIG 7.2 VIEW OF THE SAN BERNARDINO FREEWAY FROM THE SAN DIMAS BRIDGE

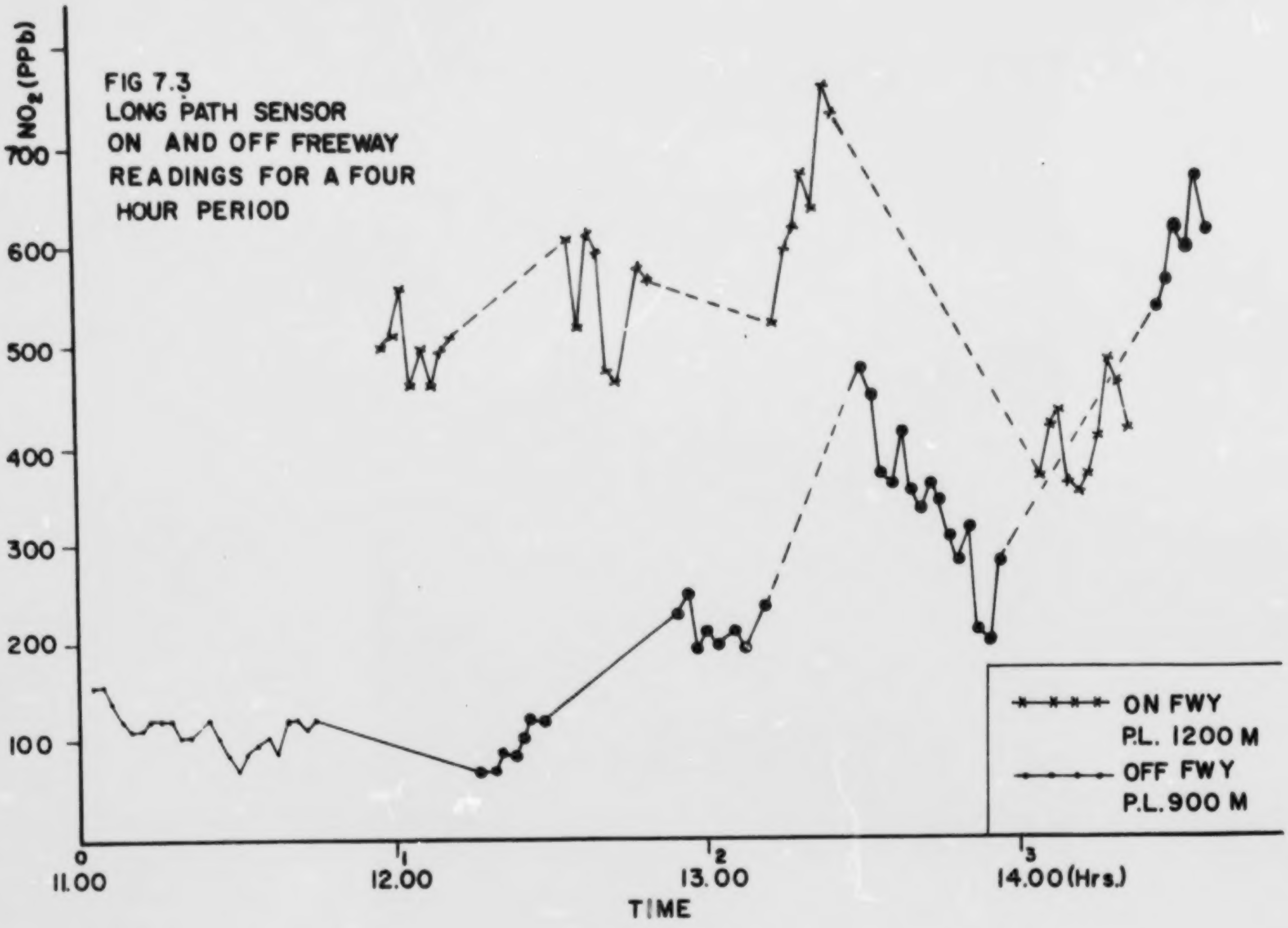


FIG 7.3
LONG PATH SENSOR
ON AND OFF FREEWAY
READINGS FOR A FOUR
HOUR PERIOD

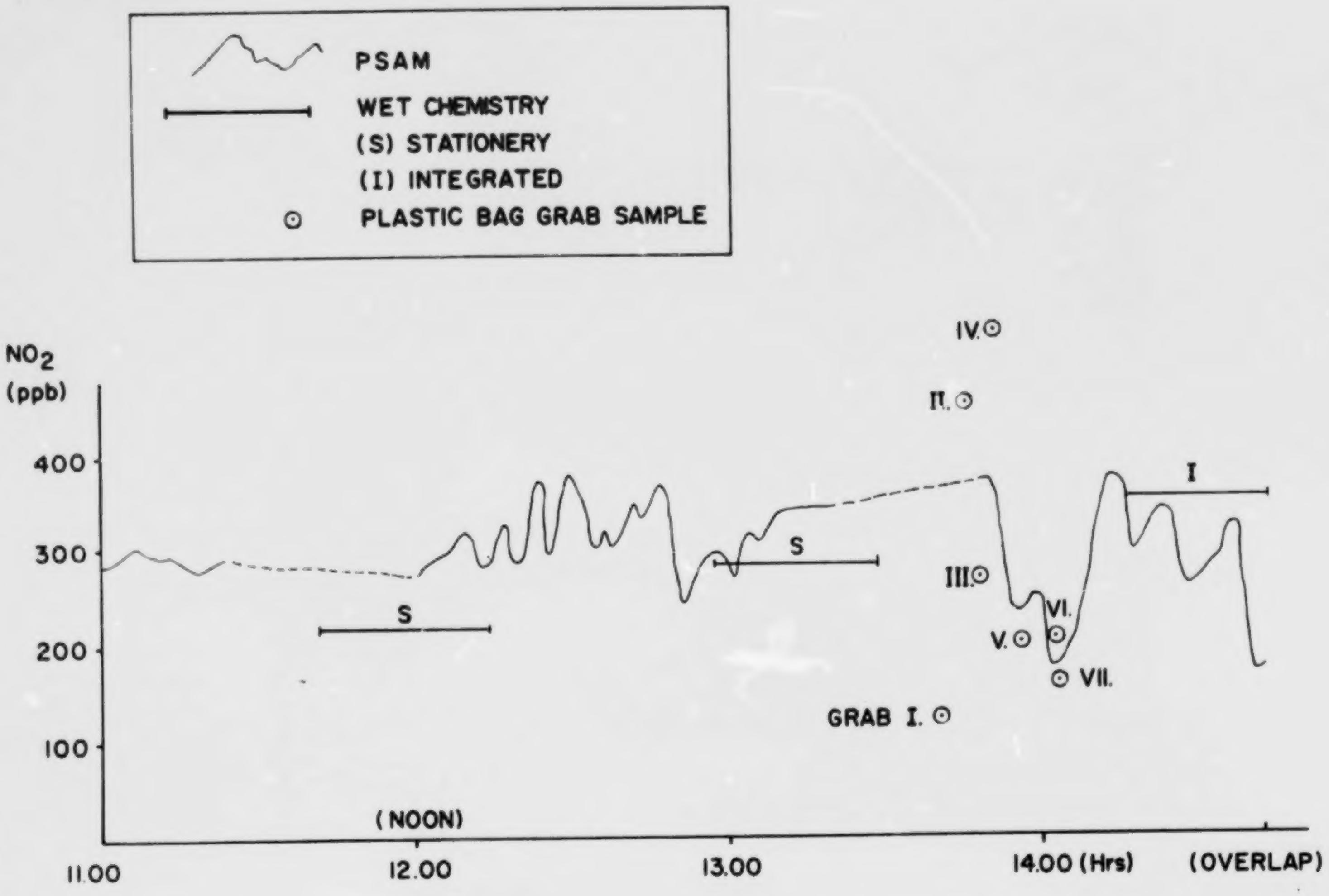


FIG 7.4 AMBIENT MONITOR ON FREEWAY SHOULDER

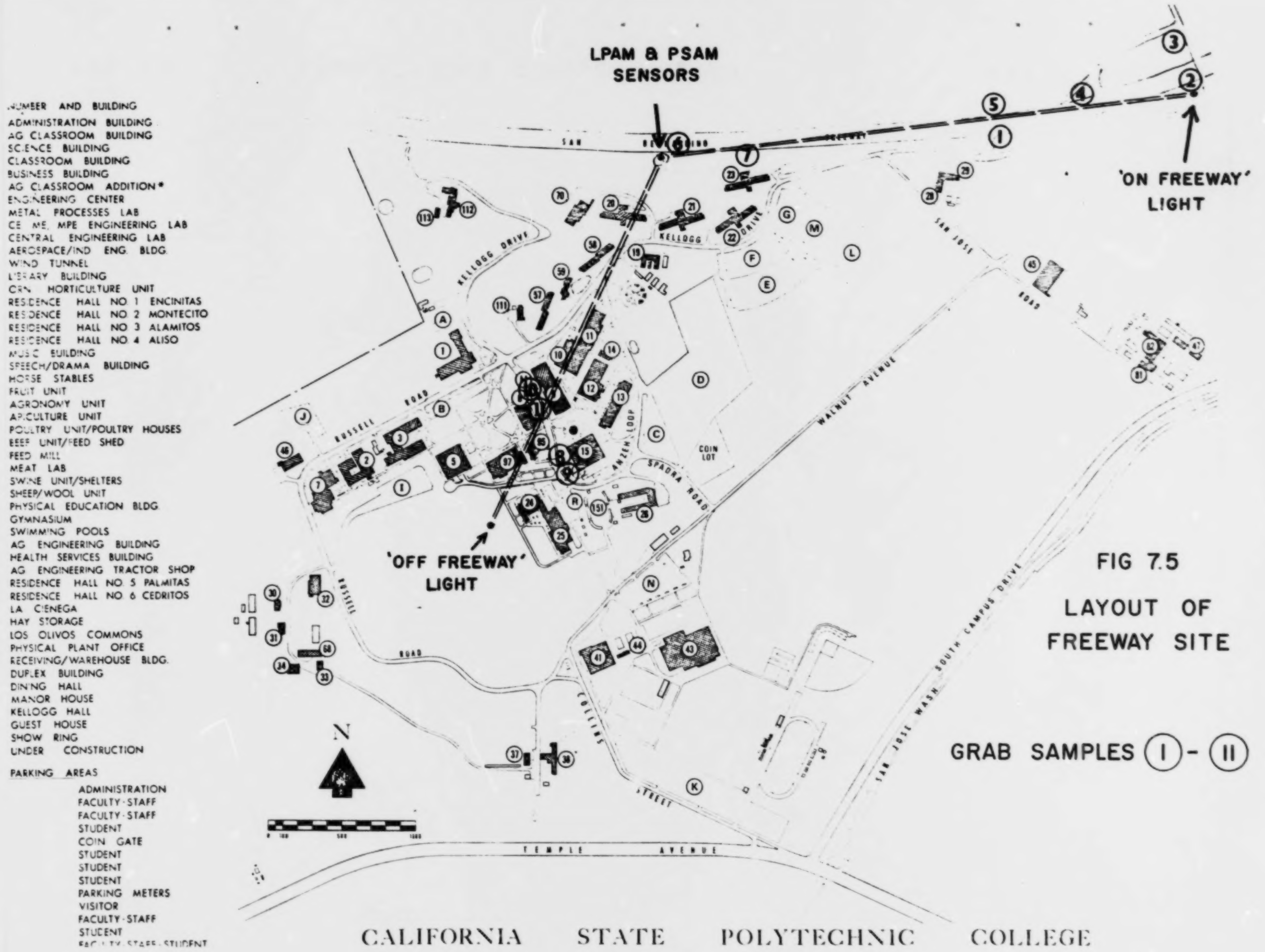

LPAM & PSAM
SENSORS
'ON FREEWAY'
LIGHT
'OFF FREEWAY'
LIGHT
GRAB SAMPLES ① - ⑪
SAN BERNARDINO FREEWAY
KELLOGG DRIVE
RUSSELL ROAD
ANZEN LOOP
SPADRA ROAD
WALNUT AVENUE
SAN JOSE ROAD
SAN JOSE WASH SOUTH CAMPUS DRIVE
COLLINS STREET
TEMPLE AVENUE
COIN LOT
N
NUMBER AND BUILDING
ADMINISTRATION BUILDING
AG CLASSROOM BUILDING
SCIENCE BUILDING
CLASSROOM BUILDING
BUSINESS BUILDING
AG CLASSROOM ADDITION *
ENGINEERING CENTER
METAL PROCESSES LAB
CE ME, MPE ENGINEERING LAB
CENTRAL ENGINEERING LAB
AEROSPACE/IND ENG. BLDG
WIND TUNNEL
LIBRARY BUILDING
ORN HORTICULTURE UNIT
RESIDENCE HALL NO. 1 ENCINITAS
RESIDENCE HALL NO. 2 MONTECITO
RESIDENCE HALL NO. 3 ALAMITOS
RESIDENCE HALL NO. 4 ALISO
MUSIC BUILDING
SPEECH/DRAMA BUILDING
HORSE STABLES
FRUIT UNIT
AGRONOMY UNIT
APICULTURE UNIT
POULTRY UNIT/POULTRY HOUSES
BEEF UNIT/FEED SHED
FEED MILL
MEAT LAB
SWINE UNIT/SHELTERS
SHEEP/WOOL UNIT
PHYSICAL EDUCATION BLDG.
GYMNASIUM
SWIMMING POOLS
AG ENGINEERING BUILDING
HEALTH SERVICES BUILDING
AG ENGINEERING TRACTOR SHOP
RESIDENCE HALL NO. 5 PALMITAS
RESIDENCE HALL NO. 6 CEDRITOS
LA CIENEGA
HAY STORAGE
LOS OLIVOS COMMONS
PHYSICAL PLANT OFFICE
RECEIVING/WAREHOUSE BLDG.
DUPLEX BUILDING
DINING HALL
MANOR HOUSE
KELLOGG HALL
GUEST HOUSE
SHOW RING
UNDER CONSTRUCTION
PARKING AREAS
ADMINISTRATION
FACULTY-STAFF
FACULTY-STAFF
STUDENT
COIN GATE
STUDENT
STUDENT
STUDENT
PARKING METERS
VISITOR
FACULTY-STAFF
STUDENT
FACULTY-STAFF-STUDENT
CALIFORNIA STATE POLYTECHNIC COLLEGE

FIG 7.5

LAYOUT OF FREEWAY SITE

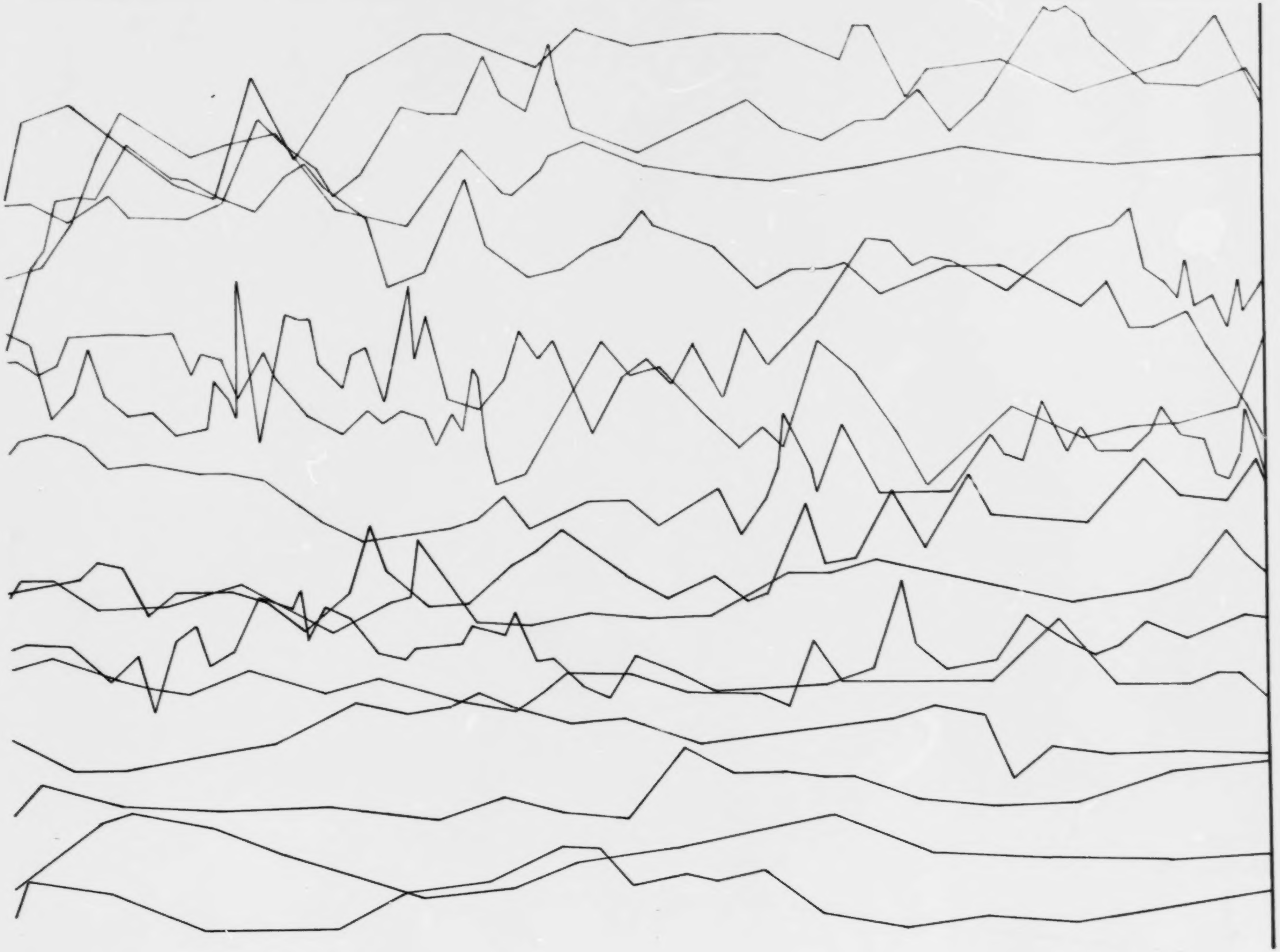


FIG 7.6 AIRCRAFT RUNS ACROSS FREEWAY JULY 10,1969

Section 8

PHASE IV C

8.1 OBJECTIVES

This ancillary experiment on horizontal profiling of nitrogen dioxide concentration at a constant altitude involved flying the airborne spectrometer repeatedly along a selected freeway approximately coincident with a wind trajectory. The objectives of the flights were to observe variations in the total gas burden with photo chemical activity and with the diurnal movements of a high NO_2 concentration parcel of air inland and back under the influence of the land-sea breeze.

8.2 INSTRUMENTATION

As in Phase II, only the airborne correlation spectrometer was involved in these tests. No surface measurements were made but data derived from LAPCD monitoring stations can be used to compare the ground level concentration variations with the total burden as recorded by the airborne instrument.

8.3 EXPERIMENTAL PROCEDURES

When this experiment was planned it was hoped that the aircraft could take off before 9:00 o'clock in the morning and make a first run during the morning rush hour. As with flights from Brackett Field, visibility below 2 miles was normally experienced until 10 or 11 a.m. which precluded the take-off of the aircraft even under special VFR conditions. A first attempt to carry out the Phase IV C flight was made on July 5th but was cancelled shortly after take off from Riverside airport on encountering low cloud over the Chino Hills.

A second attempt on July 8th was delayed by heavy haze in the morning and was abandoned after two round trips due to low cloud over the hills. The last attempt was made on July 11th, which got off to a good start and yielded three round trips during the morning. The proposed continuation after lunch had to be cancelled due to build up of cloud which developed into a severe and unseasonable thunderstorm.

In each case the aircraft flew from the Riverside Airport to one side of the Riverside Freeway through the Chino Hills over Anaheim and Seal Beach to the Pacific Ocean. Fortunately major land marks such as Disney Land and Seal Beach were noted on the record since, as we have previously noted, the flight recovery camera failed to work.

8.4 RESULTS

The vertical integrals of the NO_2 along the line from Riverside over Anaheim to Seal Beach (Long Beach) are shown in figure 8.1 - 8.3. In these figures the right hand side of the page represents Riverside, the left hand side represents Seal Beach with Anaheim approximately in the middle of the page. The vertical direction represents time and heavy oblique lines are the abscissa for zero NO_2 with the passage of time during the flight. It should be noted that in the absence of flight recovery photography the exact location of the aircraft is never known with certainty, and the ends of the flights are determined from notations made on the graph. In most cases the notation for Anaheim is also included on the record. Thus, the ends and center of the traces are reasonably accurate. For the remainder of the trace the assumption has to be made that the speed of the aircraft was constant and while this is substantially correct, small changes in wind velocity will cause minor peaks to be displaced slightly.

Figure 8.1 shows three runs made on the afternoon of July 8th in an attempt to confirm the westward movement of the polluted air mass under the influence of the afternoon land breeze. Only three runs were completed before the flight had to be aborted due to cloud build up and adverse weather forcast. Figure 8.1 shows a very irregular trace indicating abrupt changes in gas concentration except for short periods of the flight which show very steady NO_2 levels, and were recorded while the aircraft was flying over the cloud. No attempt was made to align the traces of these three flights. The NO_2 cloud which the flight was designed to follow is not as discernable on these flights as on the morning flight which followed on July 11th. On run 2, the high gas concentration was obscured by cloud and between flights 1 and 3 very little movement is discernable. By using the two constant sources which are defined more precisely in later runs to locate the Long Beach area, the gas cloud which is clearly defined in Run 3, is found to be located approximately midway between Long Beach and Anaheim where the flight path crosses the San Diego Freeway.

The data for the flight of July 11th is shown in Figures 8.2 and 8.3. Figure 8.2 shows the raw data as indicated by notations on the graph. Each of these curves show two constant sources located in the downtown area of Long Beach, and in Figure 8.3 the curves have been moved to bring these two peaks, defined as B & C vertically beneath one another. Seal Beach is now located at A.

The broad hump representing a polluted air mass seems to be located about 5 miles east of Seal Beach in the early flights and to move in an easterly direction during the course of the tests. The dotted lines represents 9 ppm meters per division and the maximum value in the polluted air mass is about 45 ppm meters. The center of the hump was located by taking the middle of the intercept of the 36 ppm meter intercept and dropping the perpendicular to the base line at the point marked,thus the movement of the center of the polluted air mass demonstrates its movement inland and the curvature of the locus suggests that the movement is accelerating. The total movement of the air mass is indicated to be 6 miles in 2.5 hours or approximately 2.5 miles per hour, which is in good agreement with normal wind velocities in the area. There is a further peak located near Riverside (designated by the letter E) which also appears to drift in an eastward direction. The velocity however is less than for the coastal air mass being only about 1 mph.

Figure 8.4 shows the profile of the second run of the July 10th flight, plotted in relation to the freeways and major intersections. There appears to be a good case for believing that the airborne spectrometer responds not only to the major polluted air mass but to local pockets of pollution in the vicinity of major freeways. The maximum vertical integral of 45 ppm meters is lower than would be expected, but as discussed in the previous chapters, considerable dilution of the signal results from light scattered within the polluted air mass and for reliable quantitative results, dilution factors have to be included.

8.5 COMPARISON WITH GROUND STATIONS

The only ground level data available at this time is from the Los Angeles County Station 72 in North Long Beach. The data for July 8th, 1969 are:-

Time	1200	1300	1400	1500	P.D.S.T.
Wind Direction	SE	SSE	SSE	W	
Wind Speed	3	4	4	10	
NO_2 PPHM	8	9	8	-	

The inversion height was 7000 ft. MSL or about 2000 m. The maximum vertical integral from figure 8.1 is approximately 25 ppm-m, or about 10 ppm-m for a single pass with allowance for the m' factor. Thus, the average concentration will be

$$10 \times \frac{100 \text{ pphm-m}}{2000 \text{ m}} = 0.5 \text{ pphm}$$

The data for July 11th, 1969 are:-

Time	0800	0900	1000	1100	1200	1300
Wind Direction	SW	W	W	SSW	S	WSW
Wind Speed	1	1	1	7	5	8
NO_2 ppm	15	25	25	12	13	11

These results indicate that the peak of the gas cloud has left station 72 by 10 a.m. and our results indicate its peak is 5 miles east of Seal Beach by 10 am. The maximum vertical integral recorded was 45 ppm-m which with due allowance for the 'm' factor, gives a burden of 20 ppm-m. The inversion height on this day was about 1500 m, so that the indicated average concentration is:

$$\frac{20 \times 100}{1500} \ \frac{\text{pphm-m}}{\text{m}} = 1.3 \text{ pphm}$$

In both these flights, the indicated average concentration is about one tenth of the recorded ground level readings. Part of this will be due to scatter/dilution of the signal and part due to non-homogenety of the gas cloud.

8.6 CONCLUSIONS

The airborne system gives precise and useful relative values of gas burden beneath the plane and the method can be used to trace gas clouds and observe gas sources. Because the influence and effects of scatter/dilution are not fully understood at this time, we cannot give quantitative data. What has resulted from our airborne work over Los Angeles is qualitative data which while being of use and interest, is somewhat limited in its direct application. Theoretical investigations into the application of this airborne survey technique to air pollution work is continuing and the achievement of quantitative measurement is considered to be with the near future state-of-the-art.

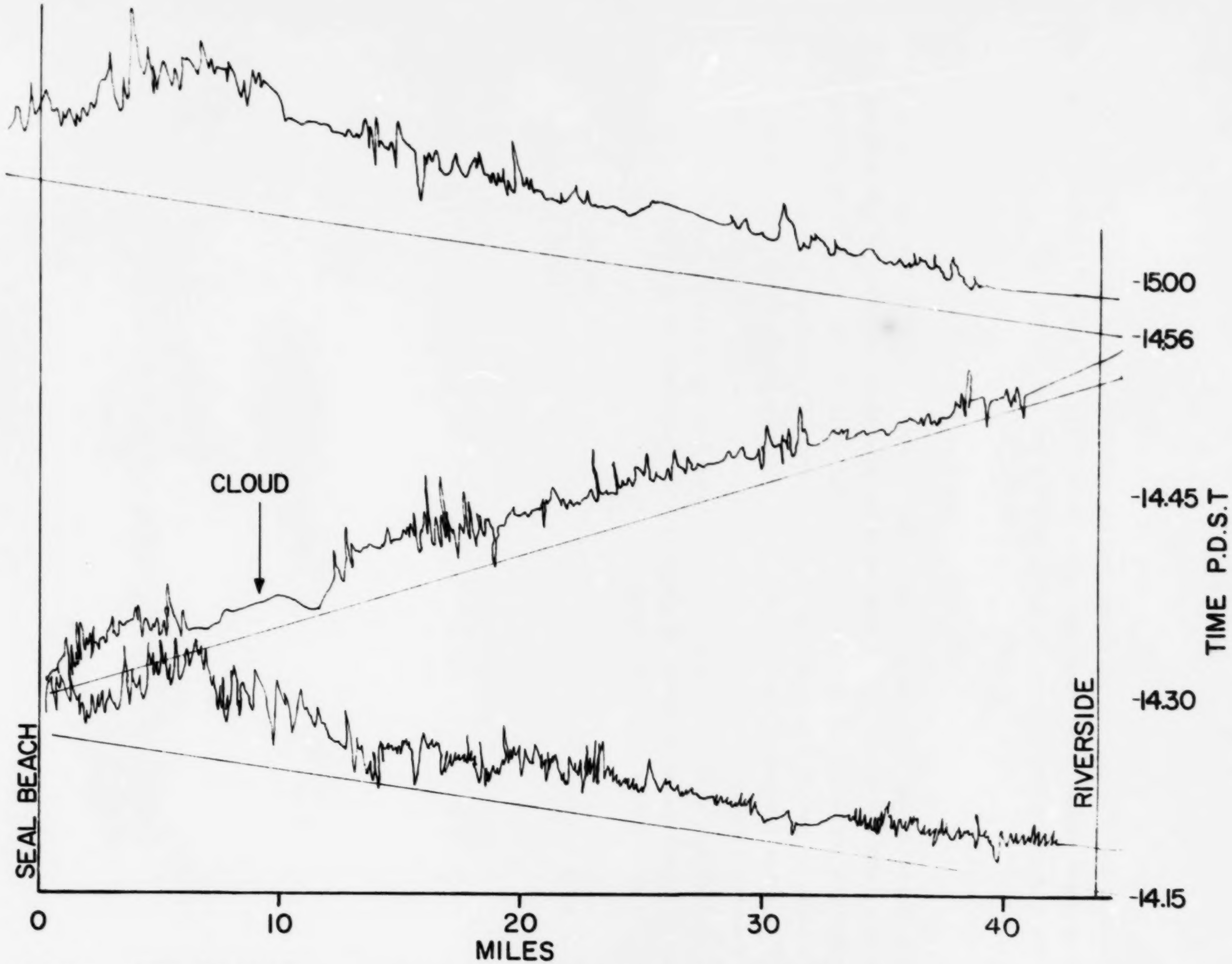


FIG 8.1 WIND TRAJECTORY FLIGHTS RIVERSIDE-LONG BEACH JULY 8, 1969

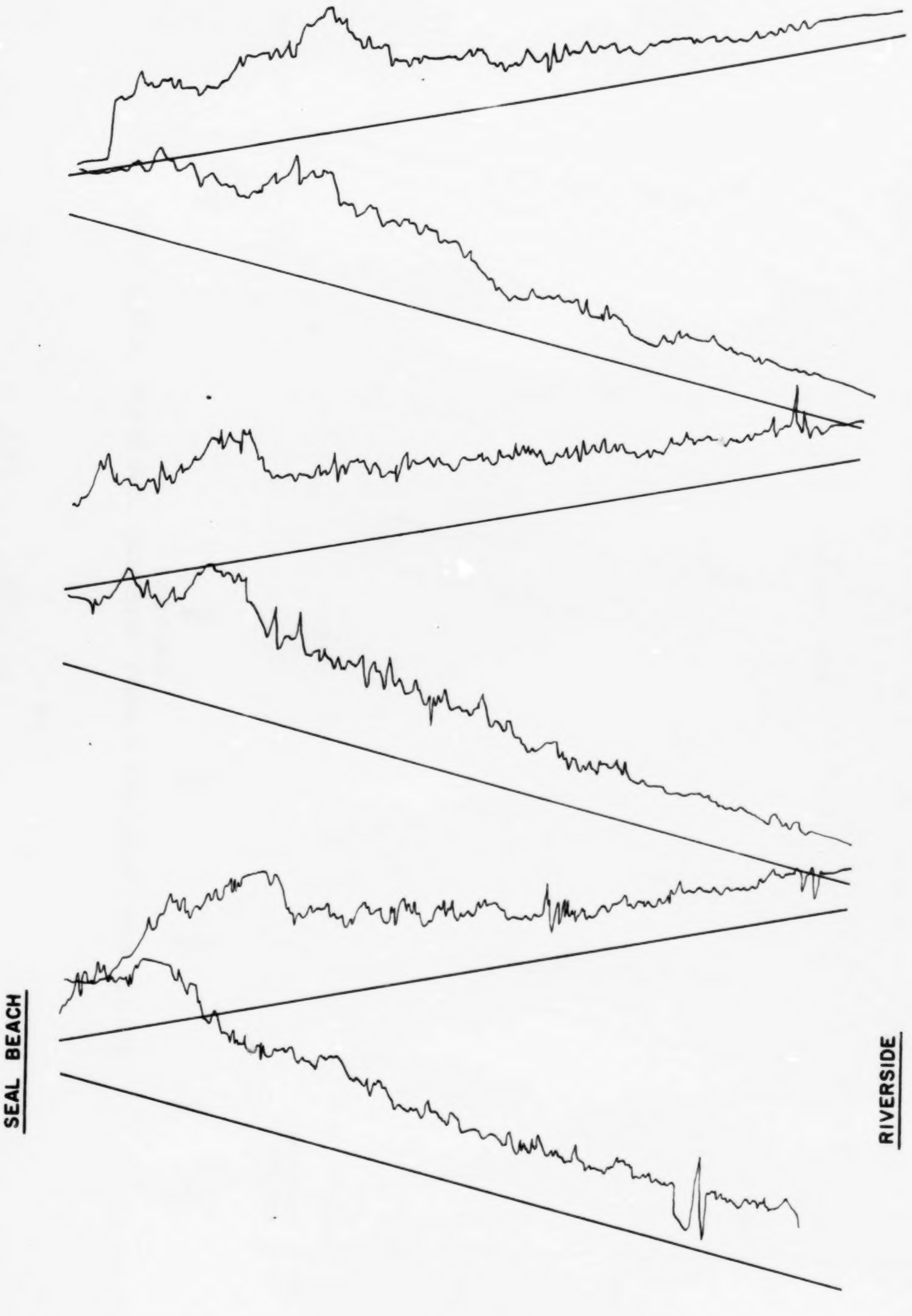


FIG. 8.2 RIVERSIDE & SEAL BEACH FLIGHT JULY 11/69

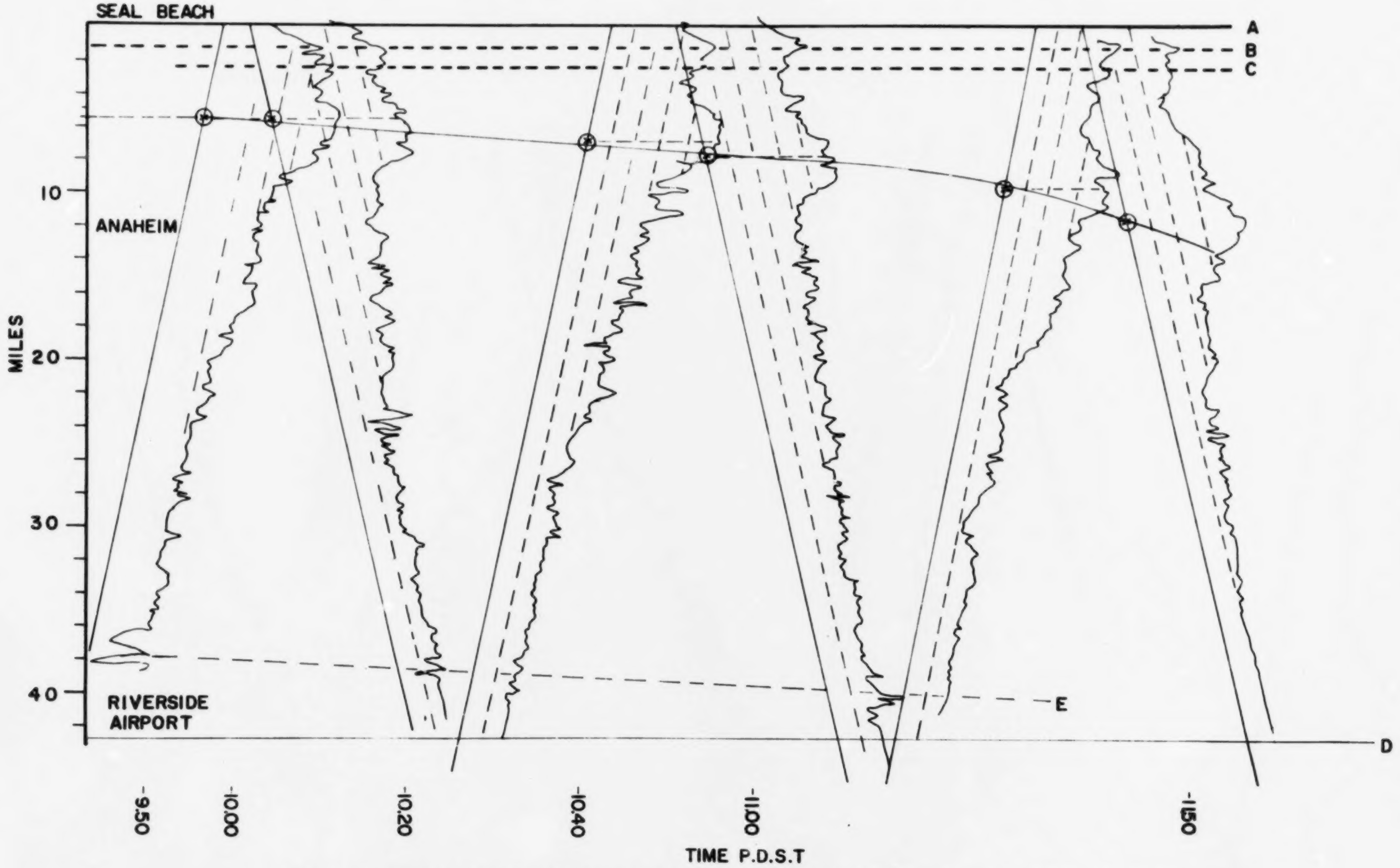


FIG 8.3 WIND TRAJECTORY FLIGHTS RIVERSIDE-LONG BEACH JULY 11, 1969

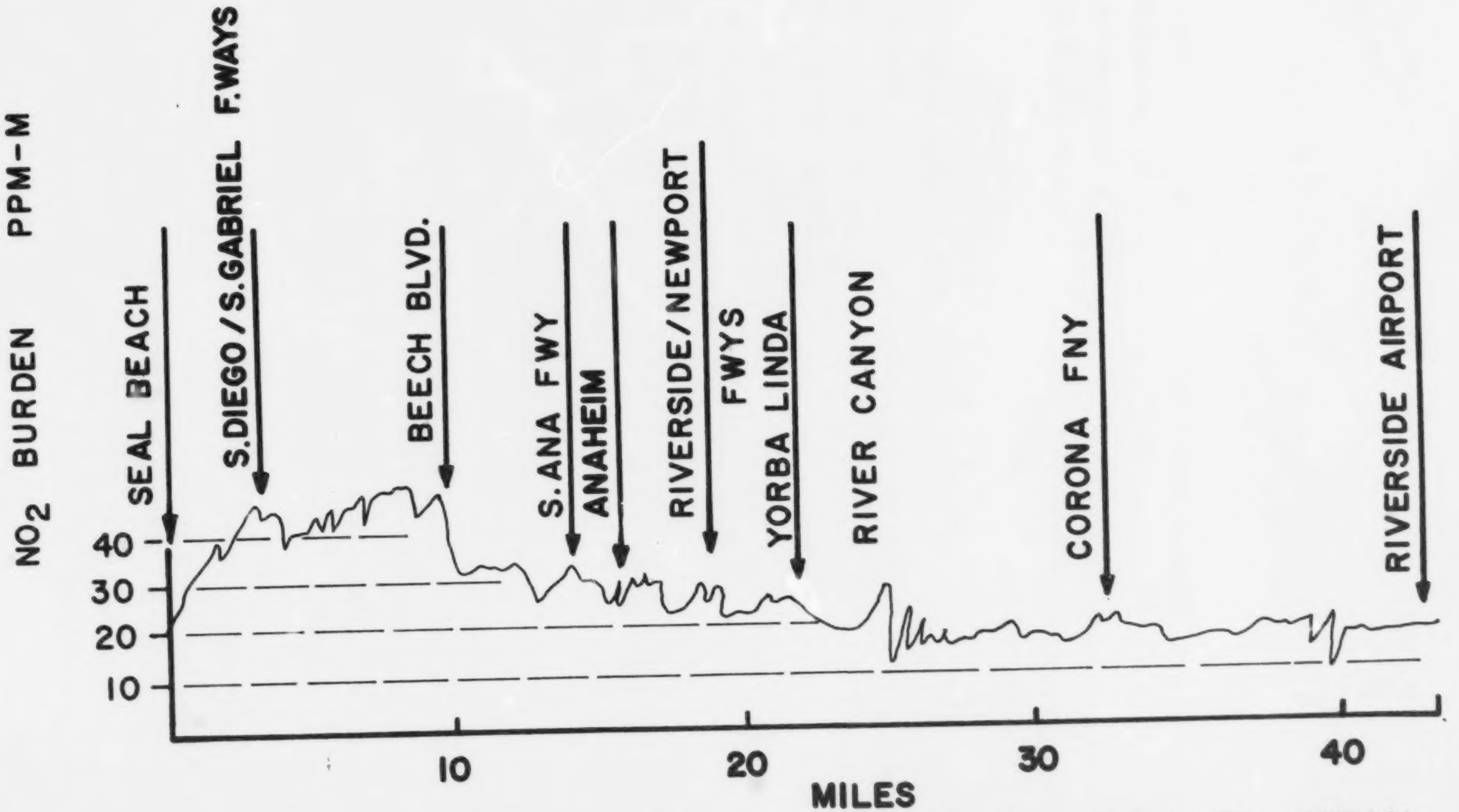


FIG. 8.4 VERTICAL INTEGRAL NO_2 IN RELATION TO URBAN LOCATIONS

Section 9

CONCLUSIONS

9.1 SUMMARY

Tests carried out under this program demonstrate that the Barringer Correlation technique yields a family of instruments which can carry out air pollution analyses not possible by other standard techniques. These instruments can be operated in several operational modes which yield air pollution data of great interest heretofore unobtainable.

In summary our Phase I work showed conclusively that the sulphur dioxide concentrations measured at the tops of various stacks under varying conditions of daylight agreed closely with concentrations recorded by the in-stack monitor located directly in the flue gas stream in the breeching. The remote sensor therefore can provide a valuable method of remote surveillance of stacks for identification of gross emitters of sulphur dioxide. Both instruments will have added value when efficient scrubbing of flue gases from high sulphur fuels becomes a commercial proposition and inefficient operation, which would release high concentrations of SO_2 into the atmosphere, could be quickly detected.

Phase II showed that the airborne system can rapidly monitor the behaviour of a plume. Changes in concentration, resulting from diffusion and turbulence or from gas phase reactions can be monitored in space and time without disturbing the system. The technique has been applied to the atmosphere oxidation of Nitric Oxide to nitrogen dioxide in a boiler stack plume and it has been shown that the reaction is too fast to be due to oxidation by atmospheric oxygen.

Phase III demonstrated the superiority of the long path ambient monitor over the point sampler when measuring sulphur dioxide in urban atmospheres, the impingement of plumes at ground level causes large variations in concentration of pollutant gases both in space and time. It has been shown that although the two units are consistent for pathlengths up to 300 meters for the long path sampler, considerable variations exist between values from the two units when the long path sampler uses pathlengths of the order of 1400 meters.

The experiments of Phase IV were carried out under conditions of light to heavy smog in southern California measuring nitrogen dioxide. Under conditions of heavy smog, the long path instruments were limited by severe loss of light due to scattering. The airborne system was also hampered by the inability of the aircraft to take off in visibility below two miles.

Phase IV A showed that the long path sampler was again more representative of an area than the point sampler when measuring NO_2 under smogy conditions. The concentration of NO_2 as measured by wet chemical analysis of grab samples was found to vary widely in both space and time and led at times to poor correlation between the long path and point sampler ambient monitor. Two problems of the long path monitor uncovered were the energy limitation due to excessive light scattering in heavy smog and the response to sunlight when looking close to the sun.

Phase IV B showed that NO_2 concentrations over the Freeway may be five times higher than the concentrations to the side of the Freeway. This is probably particularly true of a Freeway along a wind track. The effect of a cross wind in blowing NO_2 over the surrounding area has been clearly demonstrated.

The aircraft surveys in Phases IV A and B have shown that in addition to the interference with the aircraft operation, heavy smog and the intense back scatter of light from the particulate matter render the airborne data very unreliable. Qualitatively, areas of heavy NO_2 concentrations were indicated but subsequent passes failed to confirm these concentrations or to show their trajectory.

Phase IV C also suffered from particulate interference and the quantitative data is of doubtful value. However, qualitatively, the buildup of NO_2 from the coast inland, the local concentrations of the gas over major freeways and the of a large cloud of NO_2 inland under the influence of the moving landward breeze were all clearly demonstrated. Attempts to show the return of the gas cloud under the influence of the afternoon sea breeze were unsuccessful.

Parallel test with both commercially available analyzers and by wet chemical referee methods show that for all configurations but the airborne, the correlation spectrometers have an accuracy which compares favourably with the commercial alternative systems. The airborne system is limited by the dilution effect generated by scattered light from aerosols and particulates. It is primarily a comparative system only, since it does not directly give ground level concentration. The airborne platform necessitates a fast response time for the spectrometer which presently precludes the use of the slow grating sweep incorporated into the long path ambient monitor.

Section 10

ACKNOWLEDGEMENTS

The studies discussed in this report have all been carried out away from the facilities of Barringer Research Limited and we gratefully acknowledge the co-operation of the various persons and organizations who have given us access to the facilities which have made these tests possible.

- To the British American Oil Company (now Gulf Oil of Canada Ltd.) who have given us free acess to their stacks and refinery for the extensive tests carried out as the original Phase 1 of this project.
- To the Hydro Electric Power Commission of Ontario for permission to carry out stack tests on their Lakeview generating station
- To Lever Brothers of Canada Limited for permission to carry out stack tests at their Toronto factory as part of the re-run of Phase I of this project.
- To the Municipality of Metropolitan Toronto and the Commissioner of Works for permission to use their research incinerator installation at the Humberview test site to examine the behaviour of the In-Stack monitor under precisely control high temperature stack conditions.
- To Mr. Brad Drowley and the Air Pollution control division of the Ontario Government for permission to set up our equipment on the Evans Avenue site for Phase 3 and for making available records of the Beckman Coulometric SO_2 Analyzer for comparison of their results.
- To the Lyons Tea Company for permission to set up our long path sampler light source on the roof of their factory.
- To Mr. Louis J. Fuller and the staff of the Los Angeles County Air Pollution Control Dept. for their cooperation and understanding.
- To the air controllers of Brackett Field tower and March Air Force Base tower for their cooperation and help during the flights of CF OVC.

- To the president and staff of the Kellogg Campus of the California Polytechnical institute for permission to set up our equipment on their grounds; for their generous provision of scaffolding and electric power.
- to the state highway patrol for permission to collect samples along the shoulder of the San Bernadino Freeway.
- To Dr. Haagen-Smidt and his staff at Riverside for their interest and advice.
- To John Nader for his continued understanding advice and encouragement.

APPENDIX A

SO₂ CONCENTRATION (IN FLUE) VS TIME.

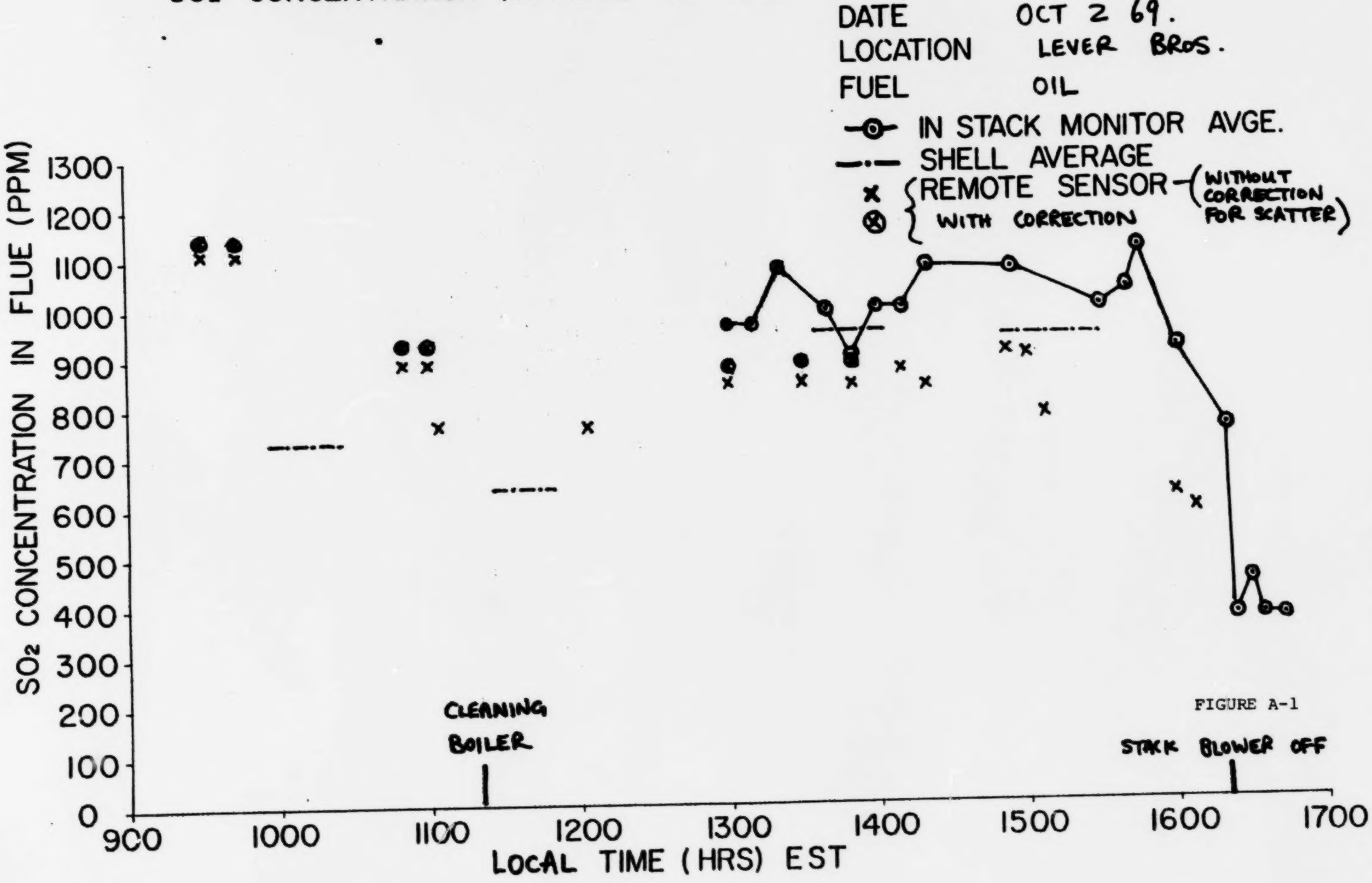


FIGURE A-1

SO_2 CONC. (AT STACK EXIT) vs RANGE
(REMOTE SENSOR)

DATE. Oct. 3/69.

LOCATION. LEVER BROS.

FUEL. OIL.

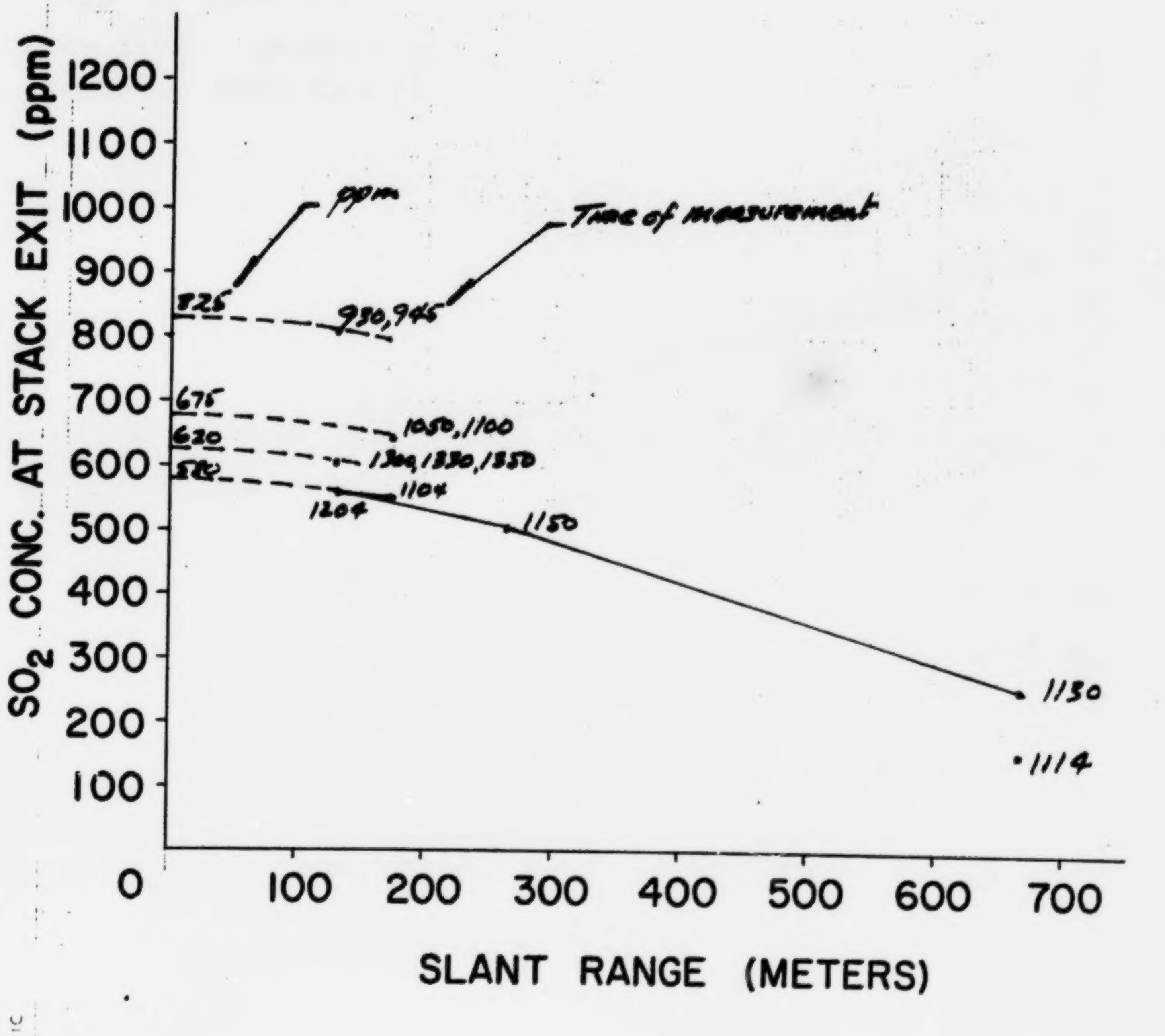


FIGURE A-2

SO_2 CONC. (AT STACK EXIT) vs RANGE
(REMOTE SENSOR)

DATE. OCT 3 '69

LOCATION. LEVER BROS.

FUEL. OIL

NOTES :-

1) IN-STACK MONITOR SHOWS 200 ppm BURST AT 13:20 – 13:25

2) VISIBILITY 6-12 MILES.

3) WIND SPEED 10-16 mph.

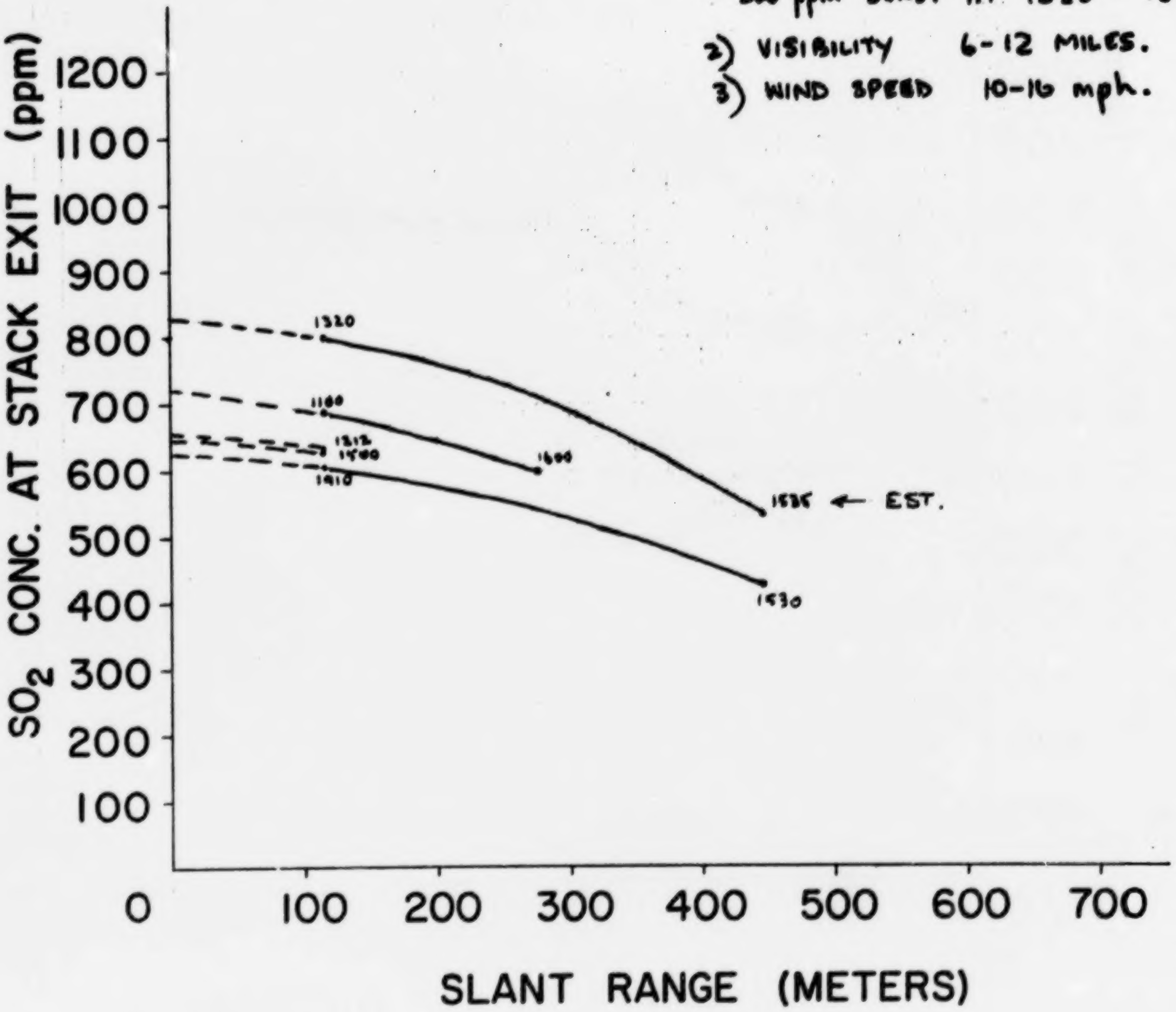


FIGURE A-3

SO₂ CONCENTRATION (IN FLUE) VS TIME.

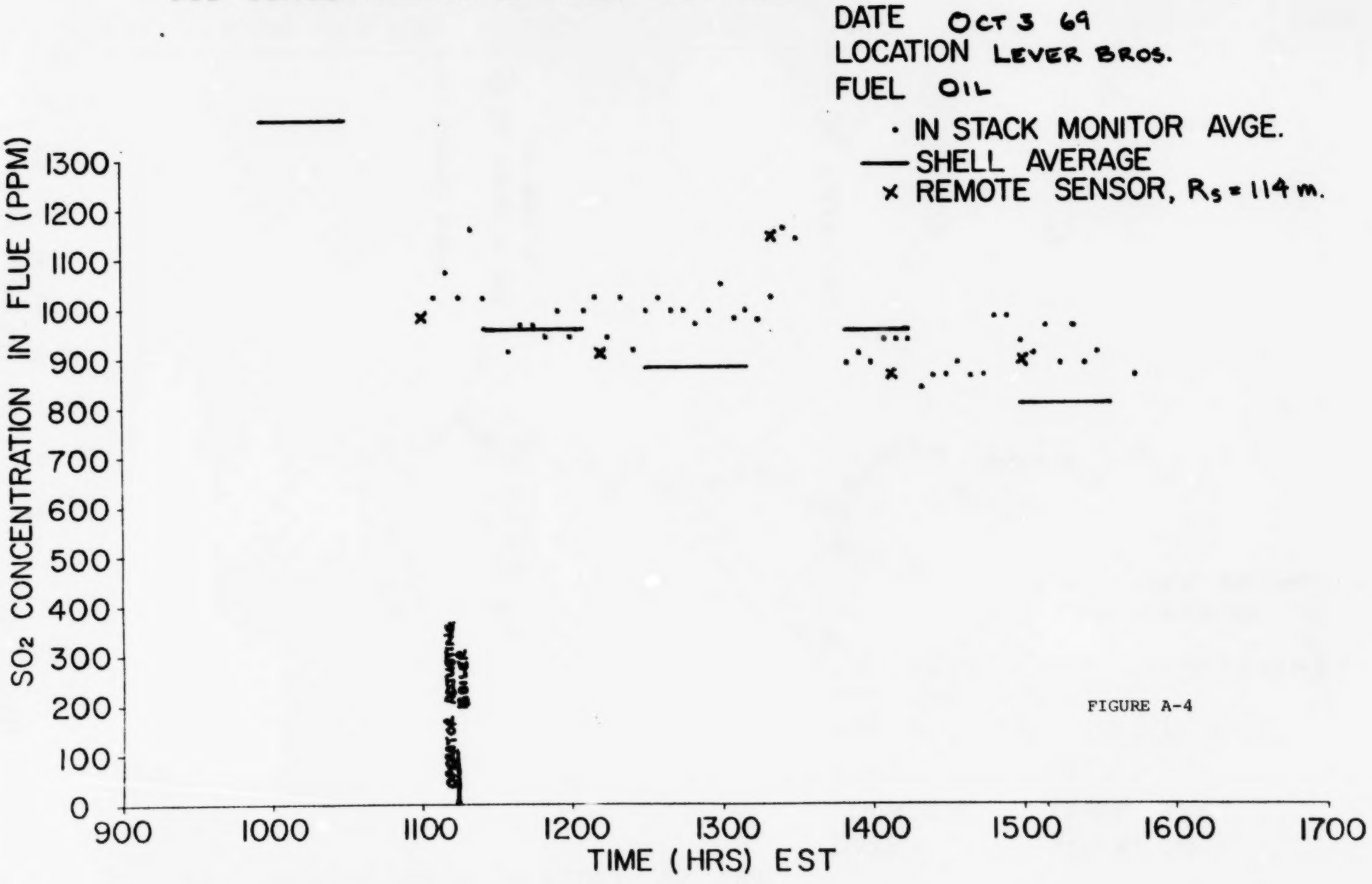


FIGURE A-4

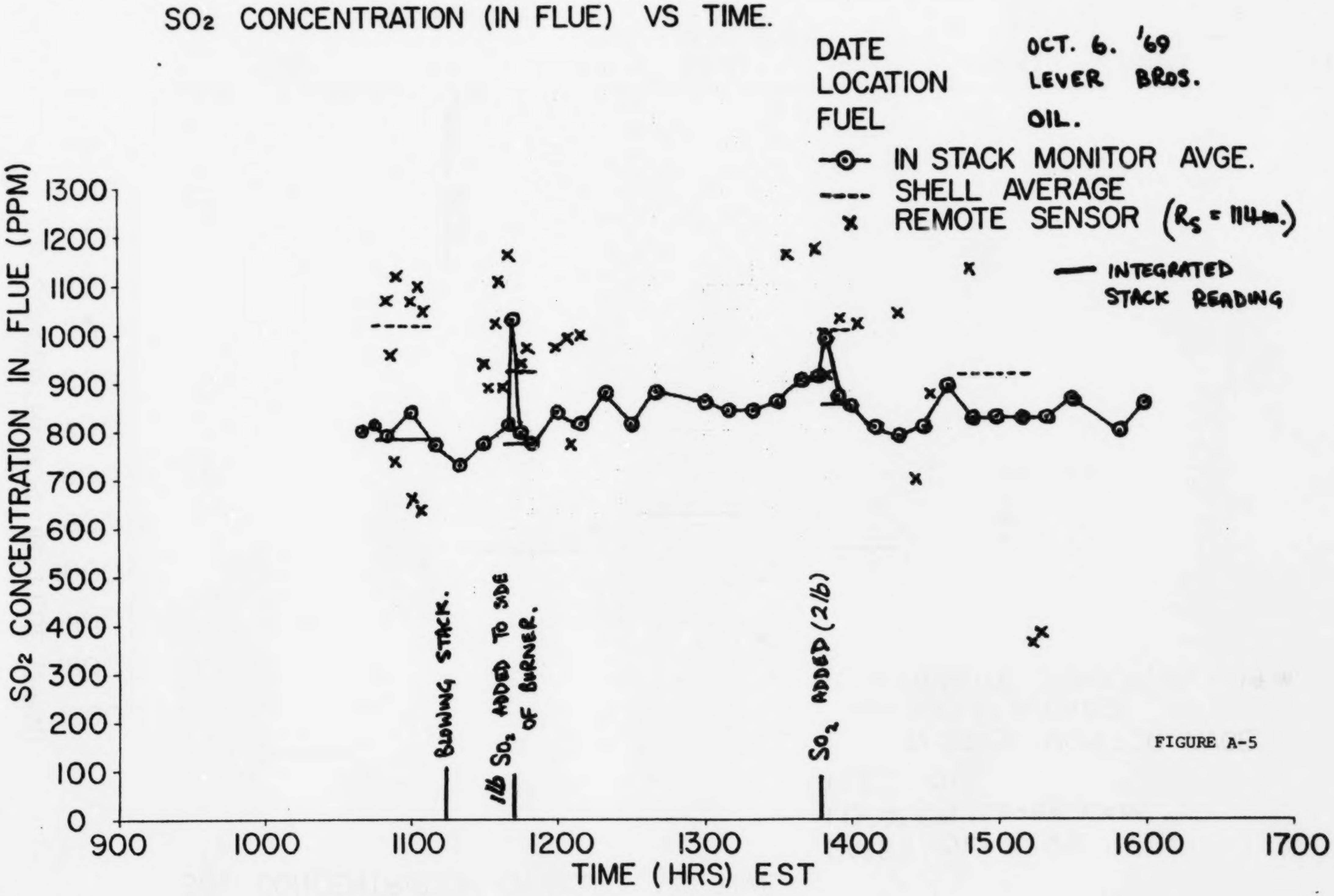
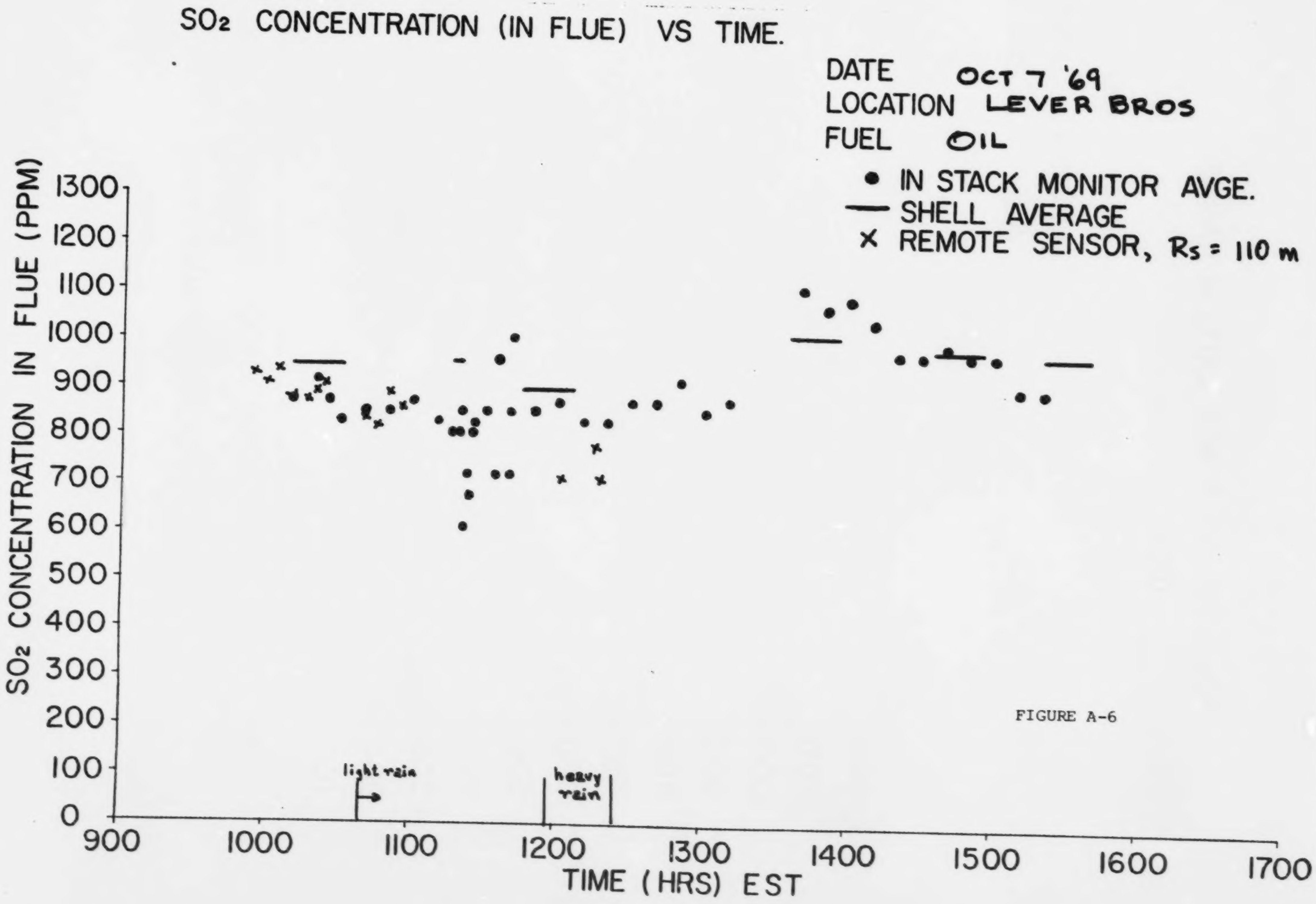

SO2 CONCENTRATION (IN FLUE) VS TIME.
DATE OCT. 6. '69
LOCATION LEVER BROS.
FUEL OIL.
IN STACK MONITOR AVGE.
SHELL AVERAGE
REMOTE SENSOR (R_S = 114m.)
INTEGRATED STACK READING
BLOWING STACK.
1lb SO2 ADDED TO SIDE OF BURNER.
SO2 ADDED (2lb)
SO2 CONCENTRATION IN FLUE (PPM)
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
900
1000
1100
1200
1300
1400
1500
1600
1700
TIME (HRS) EST

FIGURE A-5



SO₂ CONCENTRATION (IN FLUE) VS TIME.

FIGURE A-6

SO_2 CONC. (AT STACK EXIT) vs RANGE
(REMOTE SENSOR)

DATE. OCT. 7 '69

LOCATION. LEVERS

FUEL. OIL

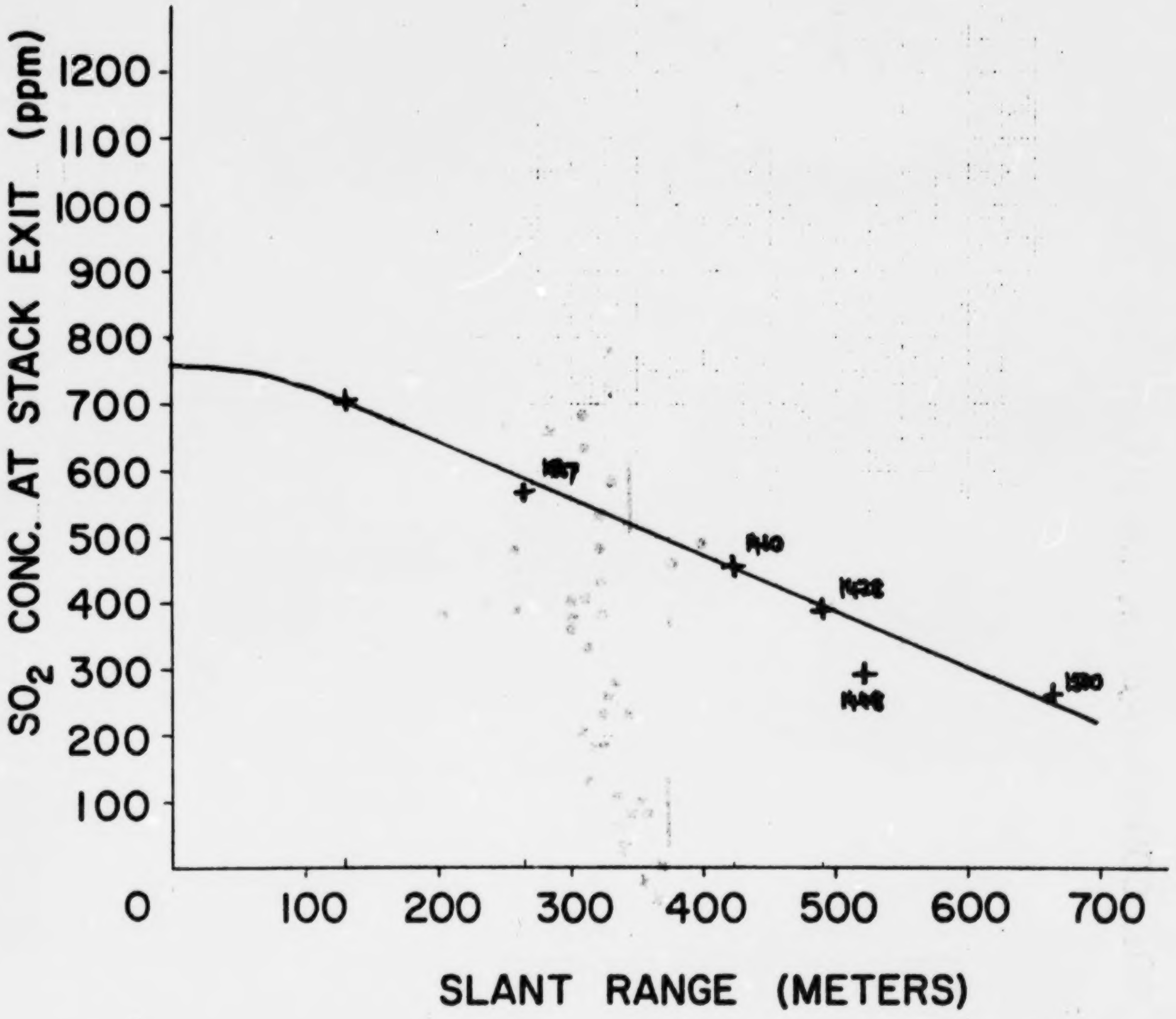


FIGURE A-7

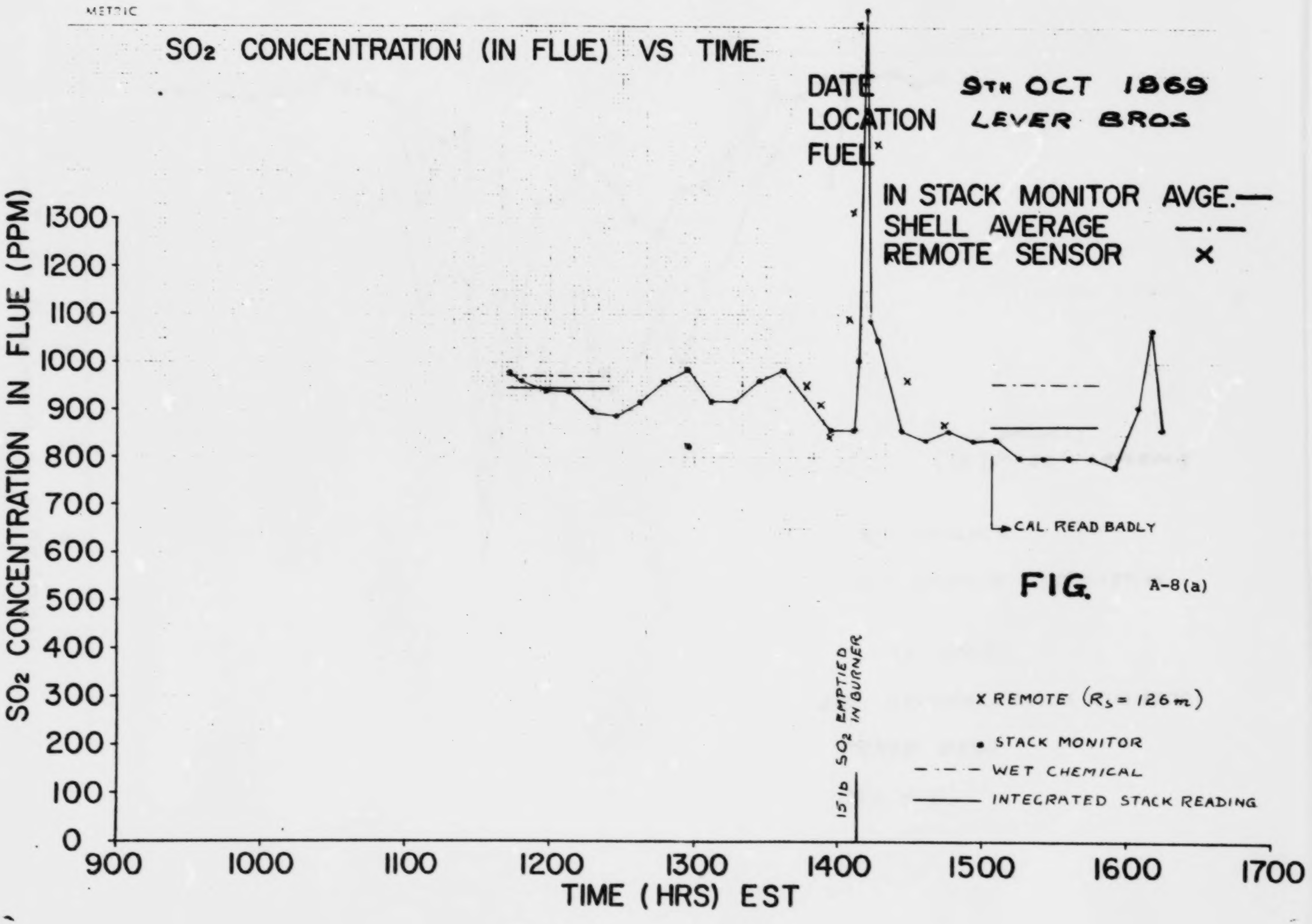
METRIC
SO₂ CONCENTRATION (IN FLUE) VS TIME.
DATE 9TH OCT 1869
LOCATION LEVER BROS
FUEL
IN STACK MONITOR AVGE. —
SHELL AVERAGE —·—
REMOTE SENSOR ×
SO₂ CONCENTRATION IN FLUE (PPM)
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
900
1000
1100
1200
1300
1400
1500
1600
1700
TIME (HRS) EST
15 lb SO₂ EMPTIED IN BURNER
CAL. READ BADLY
× REMOTE (Rs = 126 m)
• STACK MONITOR
—·— WET CHEMICAL
—— INTEGRATED STACK READING

FIG. A-8(a)

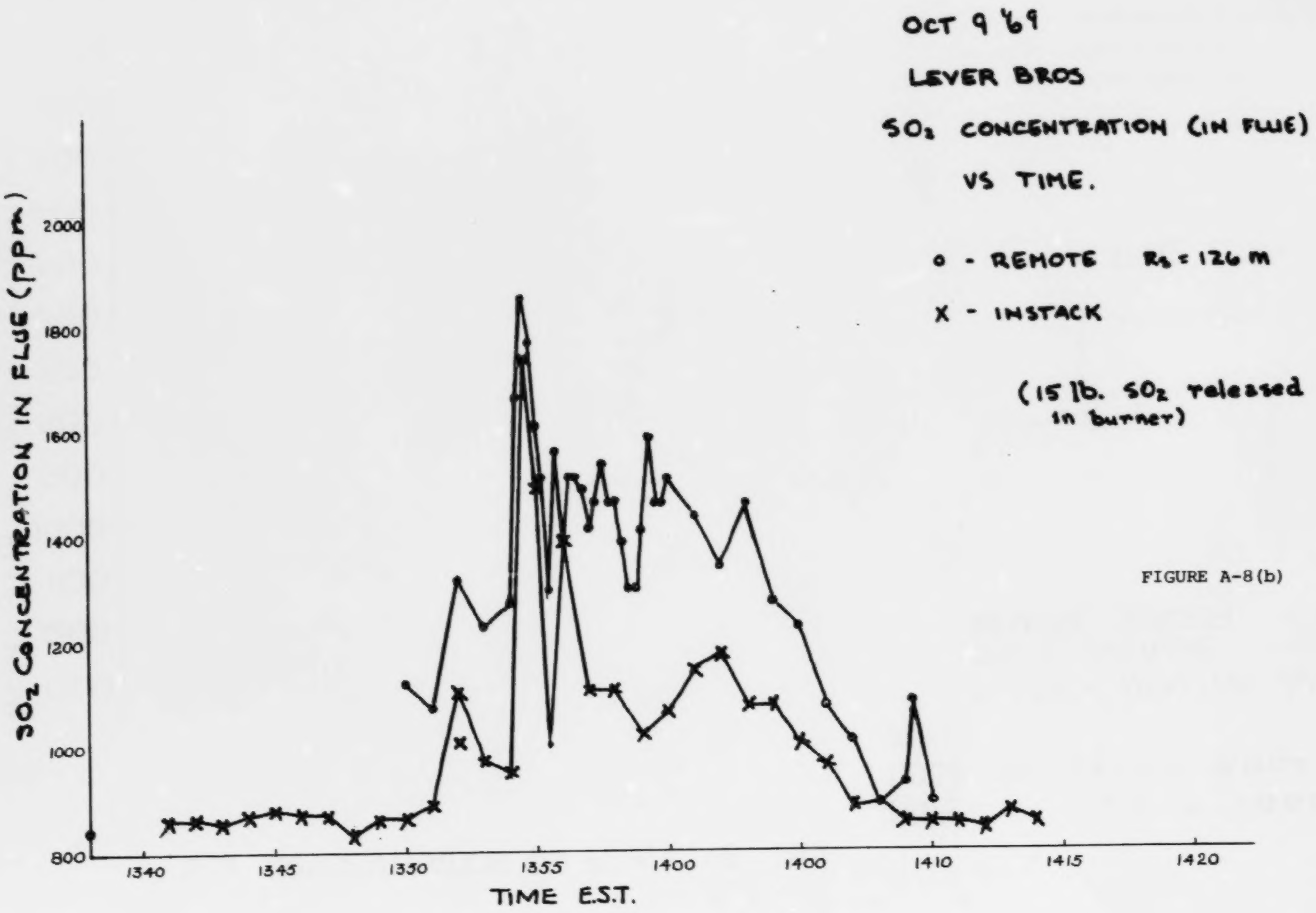

OCT 9 '69
LEVER BROS
SO_2 CONCENTRATION (IN FLUE)
VS TIME.
o - REMOTE R_s = 126 m
X - INSTACK
(15 lb. SO_2 released in burner)
SO_2 CONCENTRATION IN FLUE (ppm)
800
1000
1200
1400
1600
1800
2000
1340
1345
1350
1355
1400
1400
1410
1415
1420
TIME E.S.T.

FIGURE A-8(b)

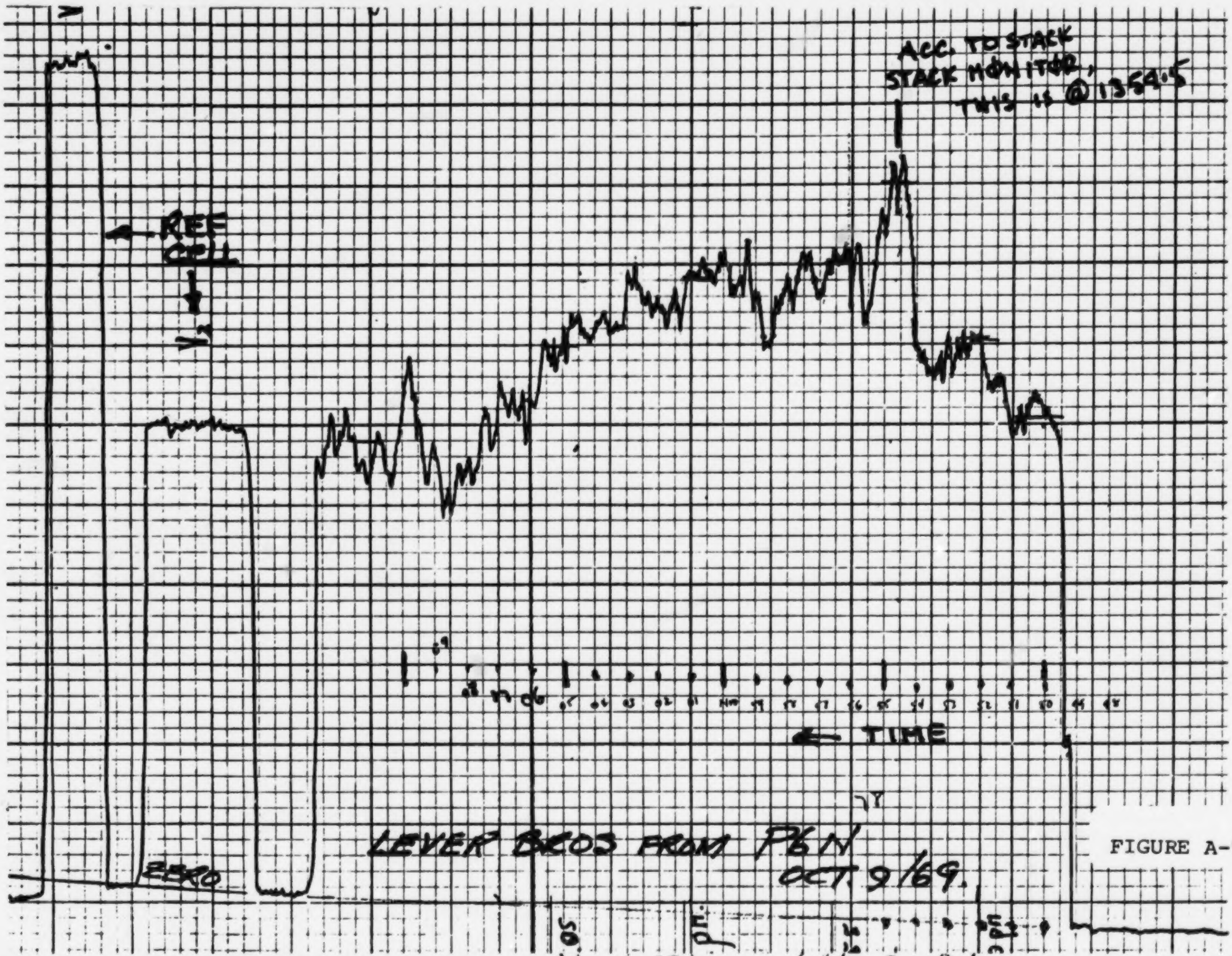


FIGURE A-9(a)

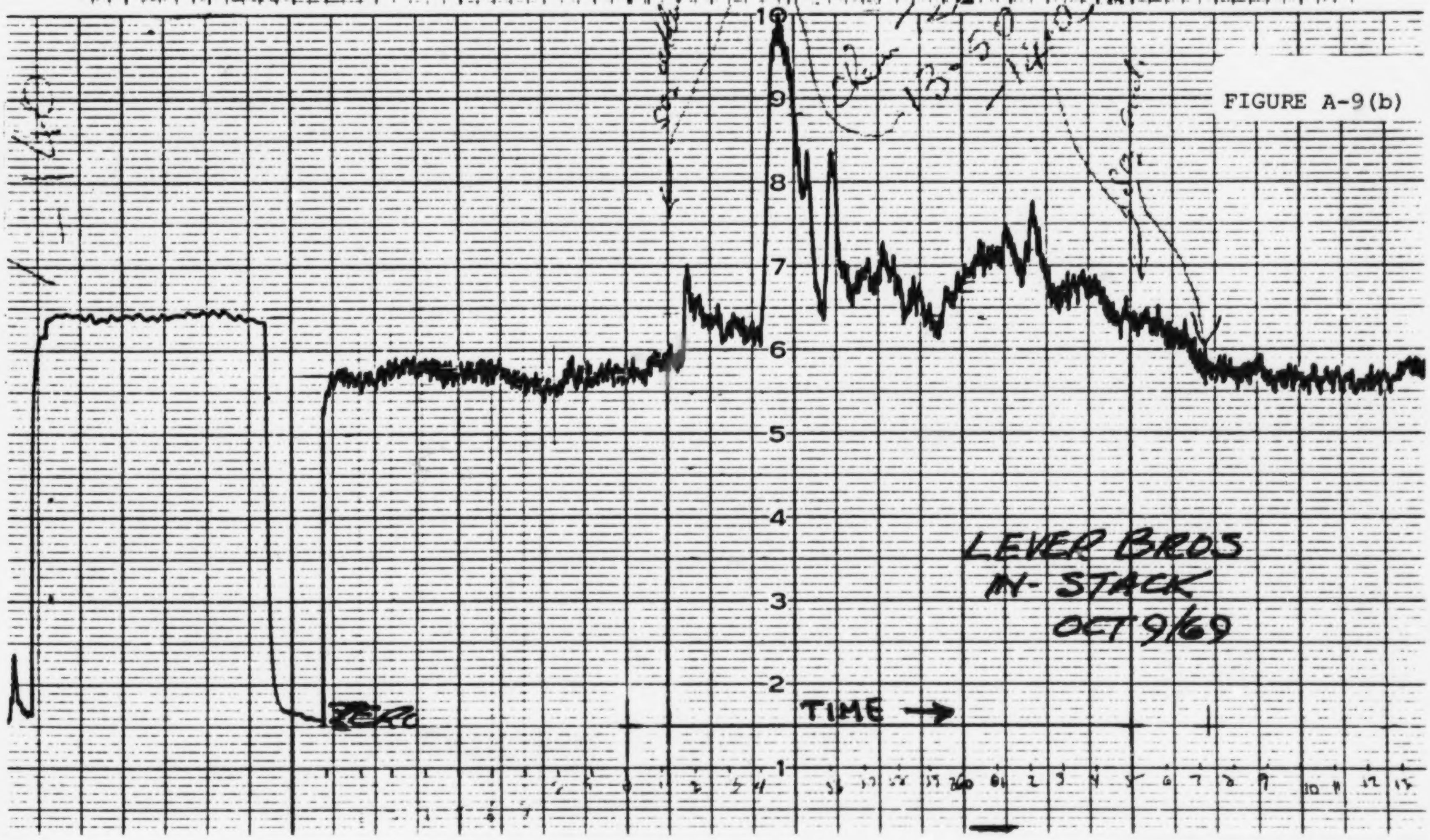


FIGURE A-9(b)

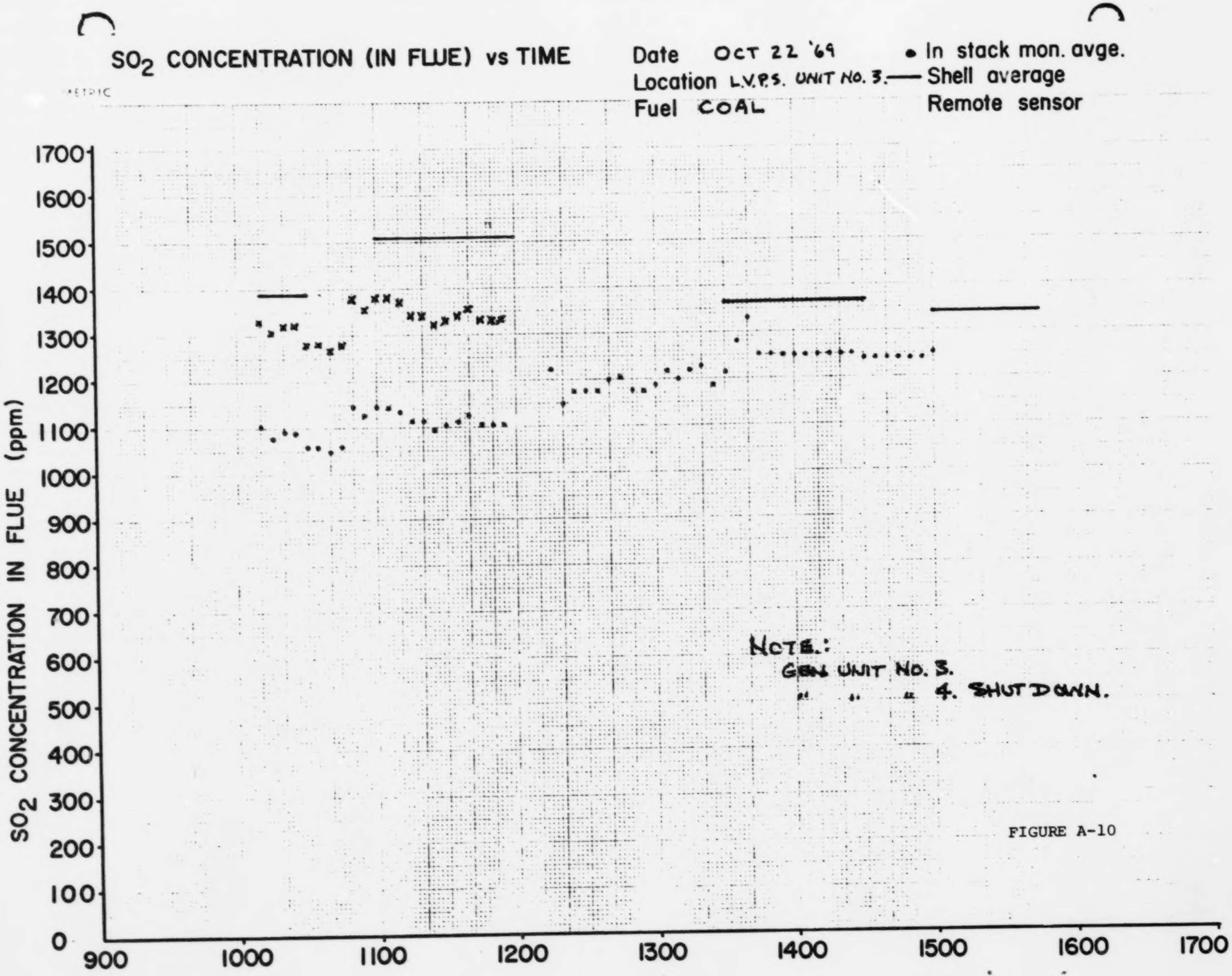
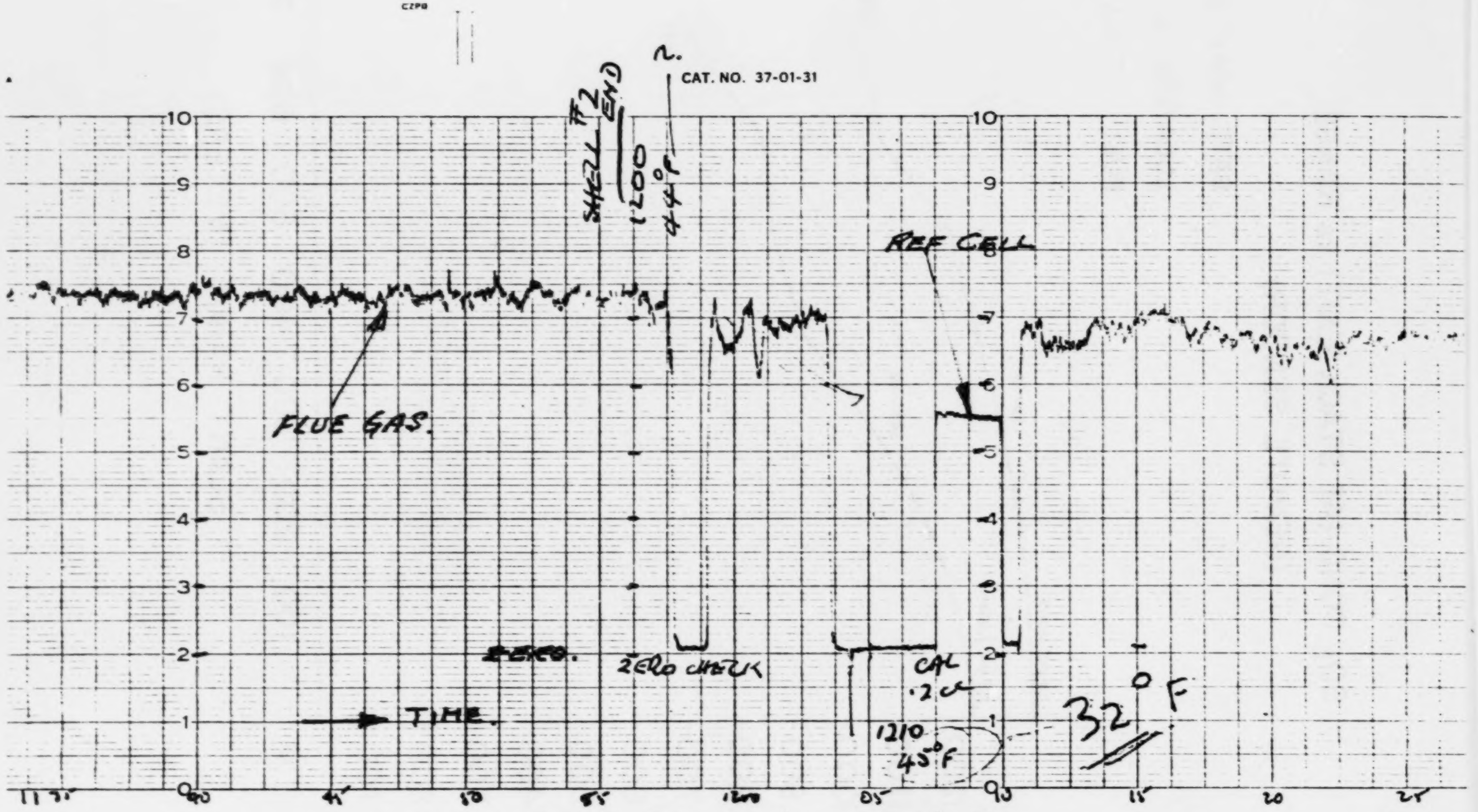

SO$_2$ CONCENTRATION (IN FLUE) vs TIME
Date OCT 22 '69
Location L.V.P.S. UNIT NO. 3.
Fuel COAL
● In stack mon. avge.
— Shell average
Remote sensor
SO$_2$ CONCENTRATION IN FLUE (ppm)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
900
1000
1100
1200
1300
1400
1500
1600
1700
NOTE:
GEN UNIT NO. 3.
" " " 4. SHUTDOWN.

FIGURE A-10



LAKEVIEW GEN. STATION UNIT No. 3.

IN-STACK CHART

FIGURE A-11

SO_2 CONC. (AT STACK EXIT) vs RANGE
(REMOTE SENSOR)

DATE. NOV 24 '69

LOCATION. L. V. P. S.

FUEL. COAL

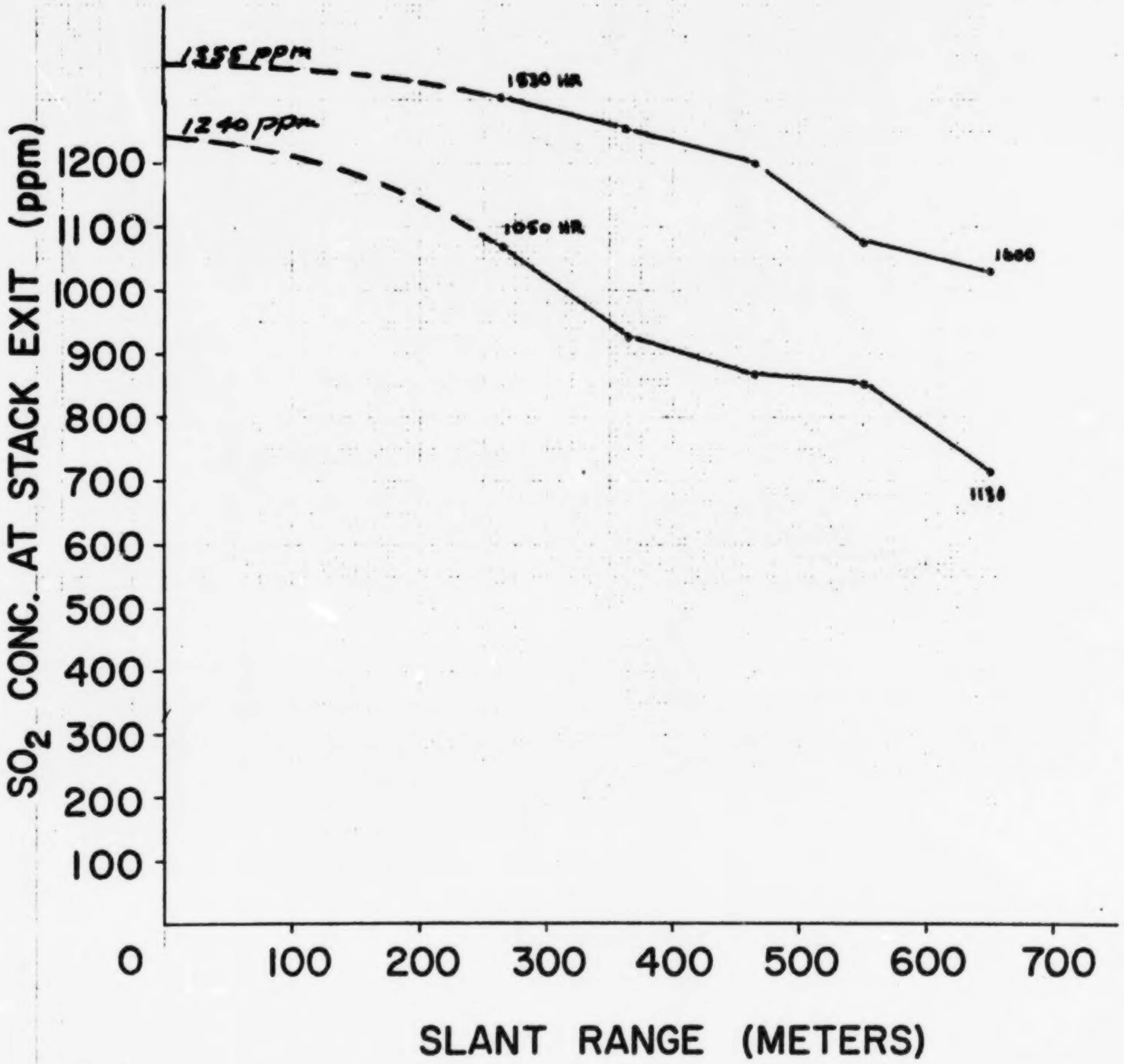


FIGURE A-12

SO_2 CONCENTRATION (IN FLUE) vs TIME

Date Nov. 24 69
Location L.V.P.S.
Fuel COAL

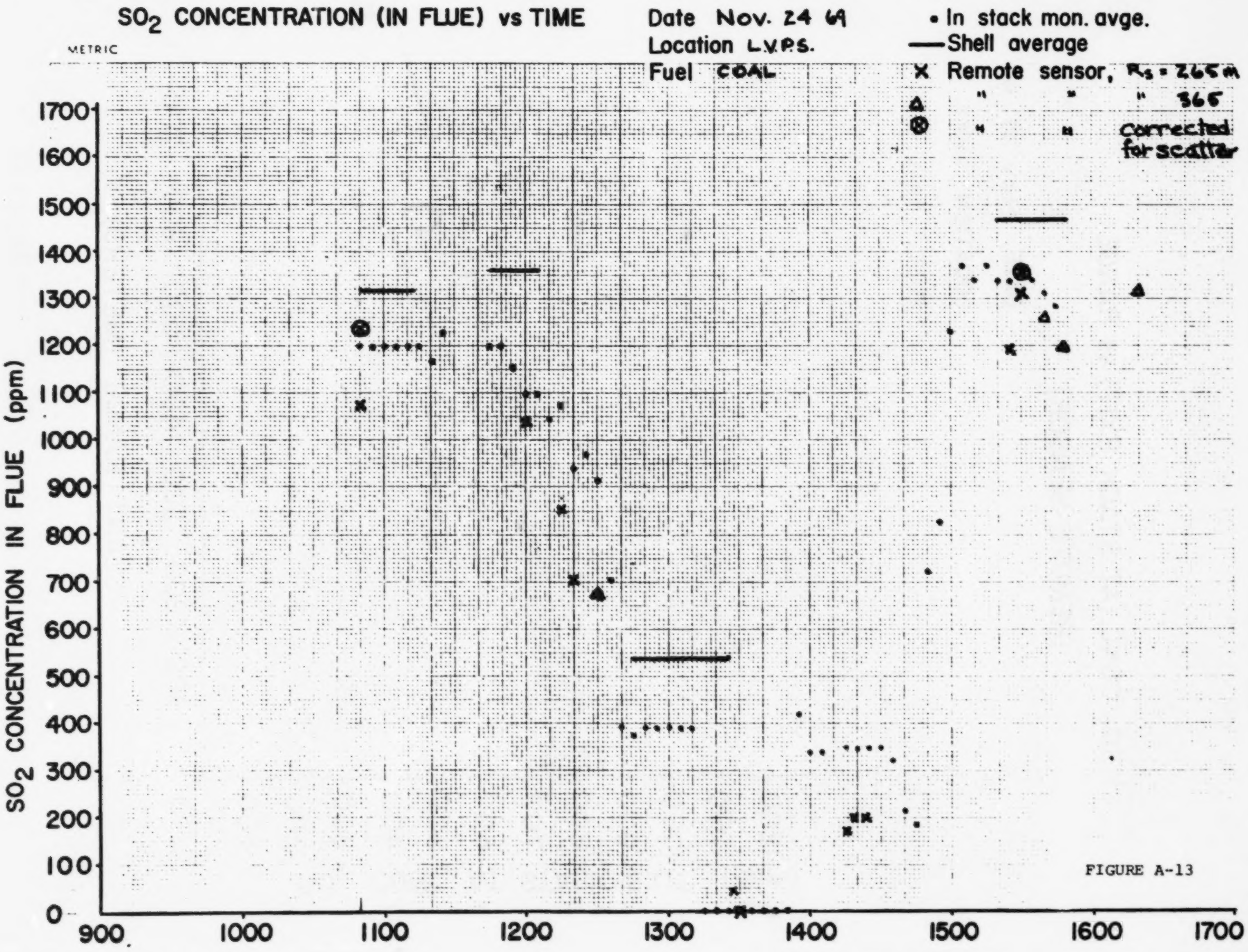


FIGURE A-13

SO_2 CONC. (AT STACK EXIT) vs RANGE
(REMOTE SENSOR)

DATE. NOV 27 69
LOCATION. L.V.P.S.
FUEL. COAL

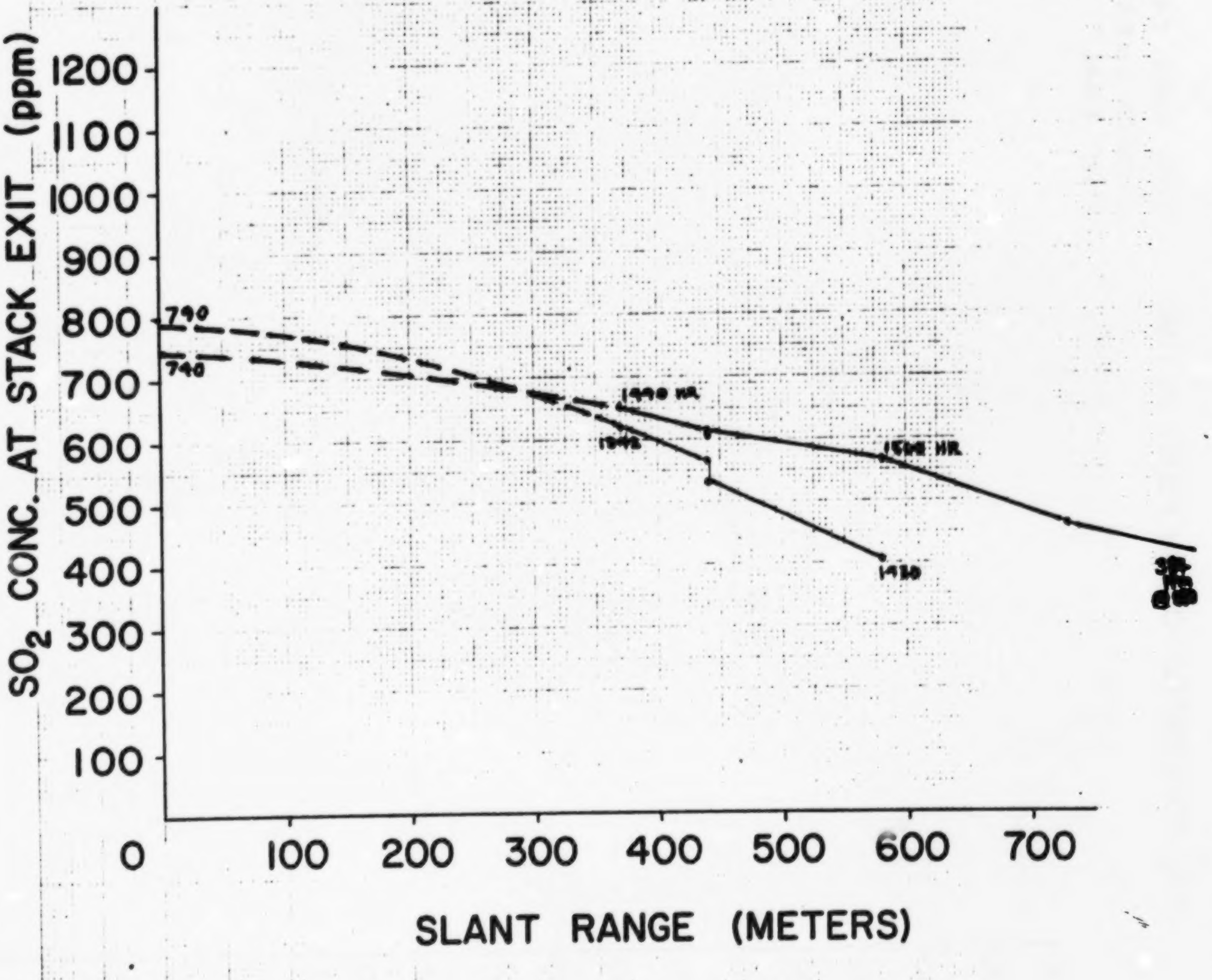
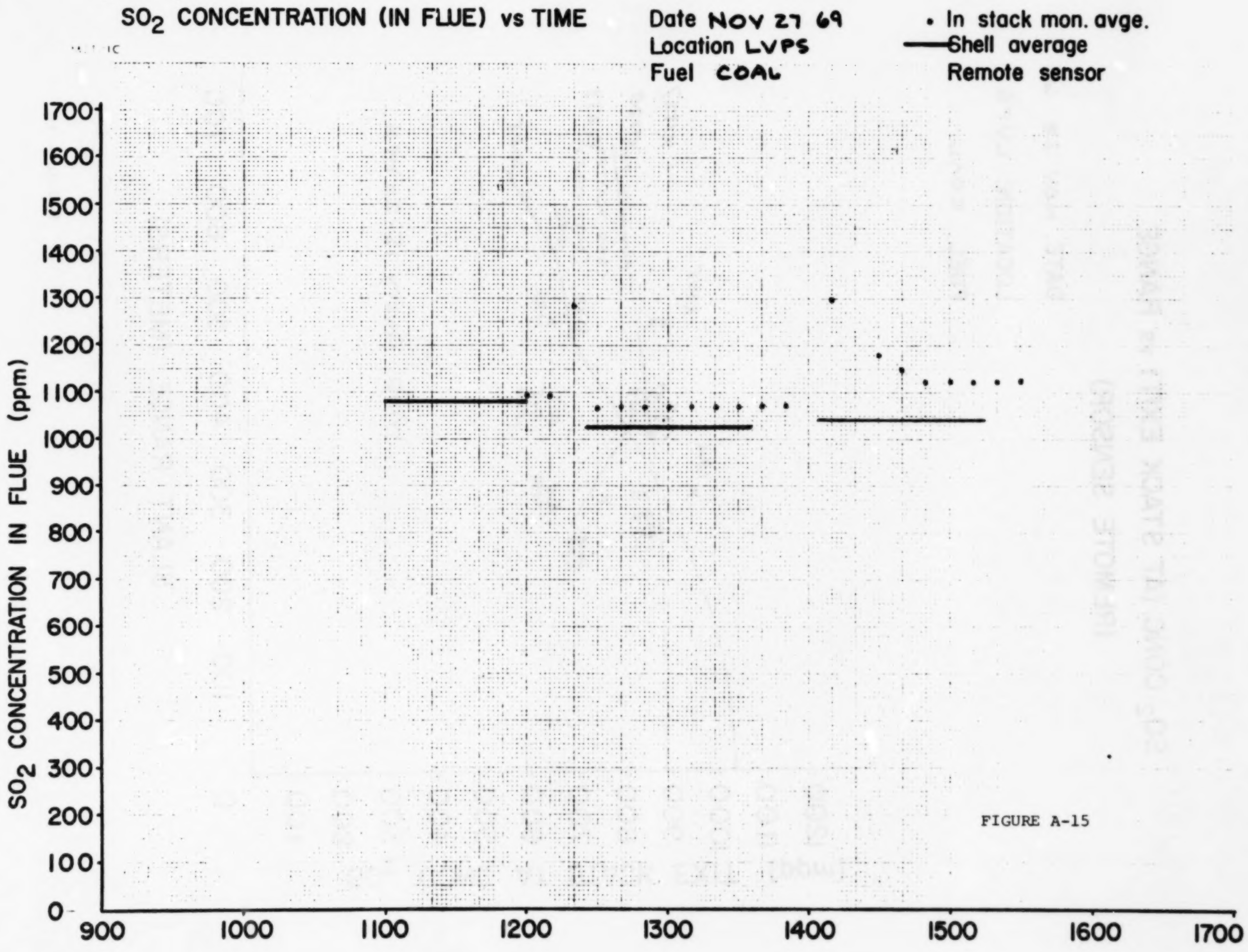


FIGURE A-14



SO$_2$ CONCENTRATION (IN FLUE) vs TIME

Date NOV 27 69
Location LVPS
Fuel COAL

FIGURE A-15

SO_2 CONC. (AT STACK EXIT) vs RANGE
(REMOTE SENSOR)

DATE. NOV 28 69

LOCATION. LVPS

FUEL. COAL

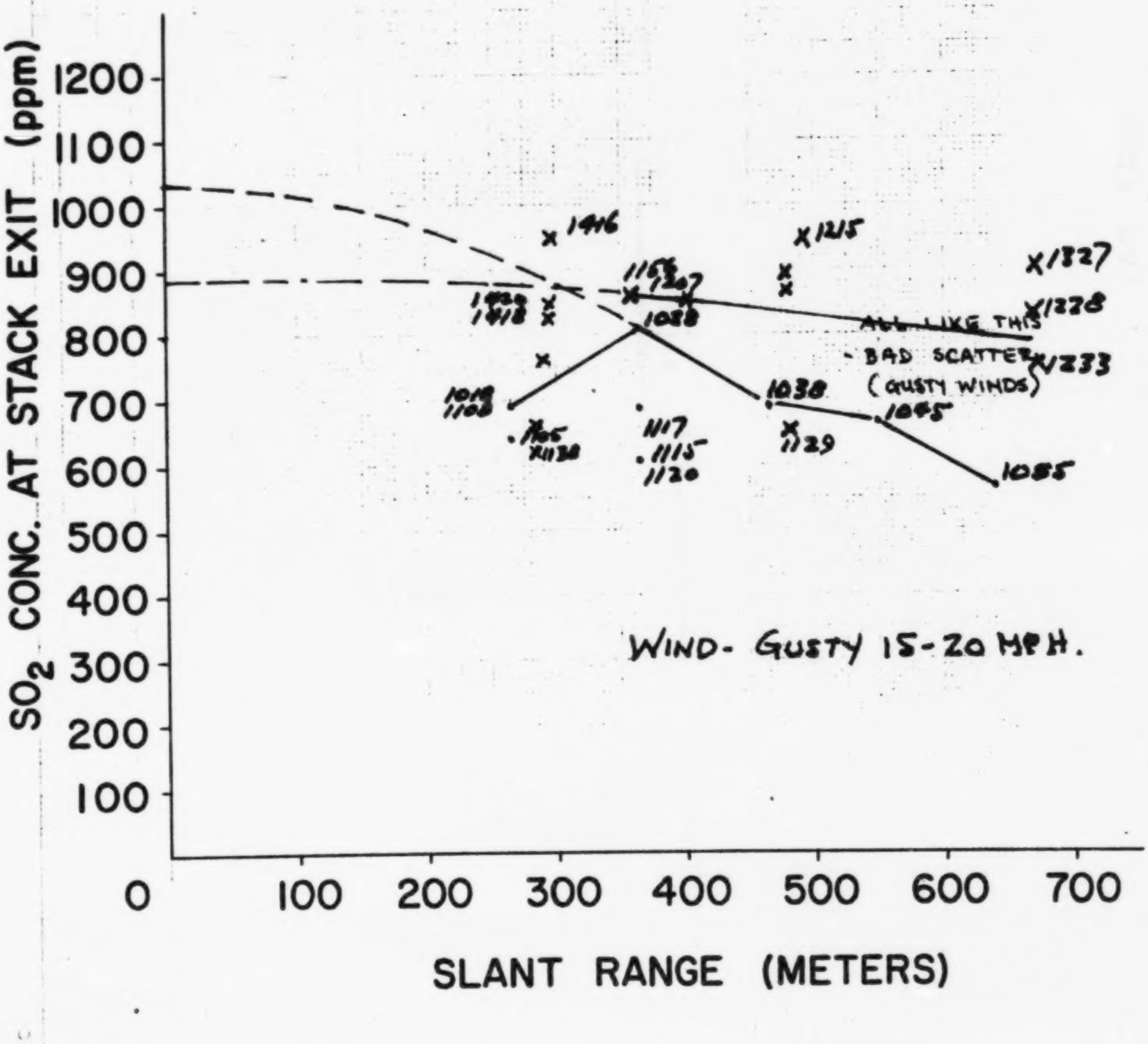
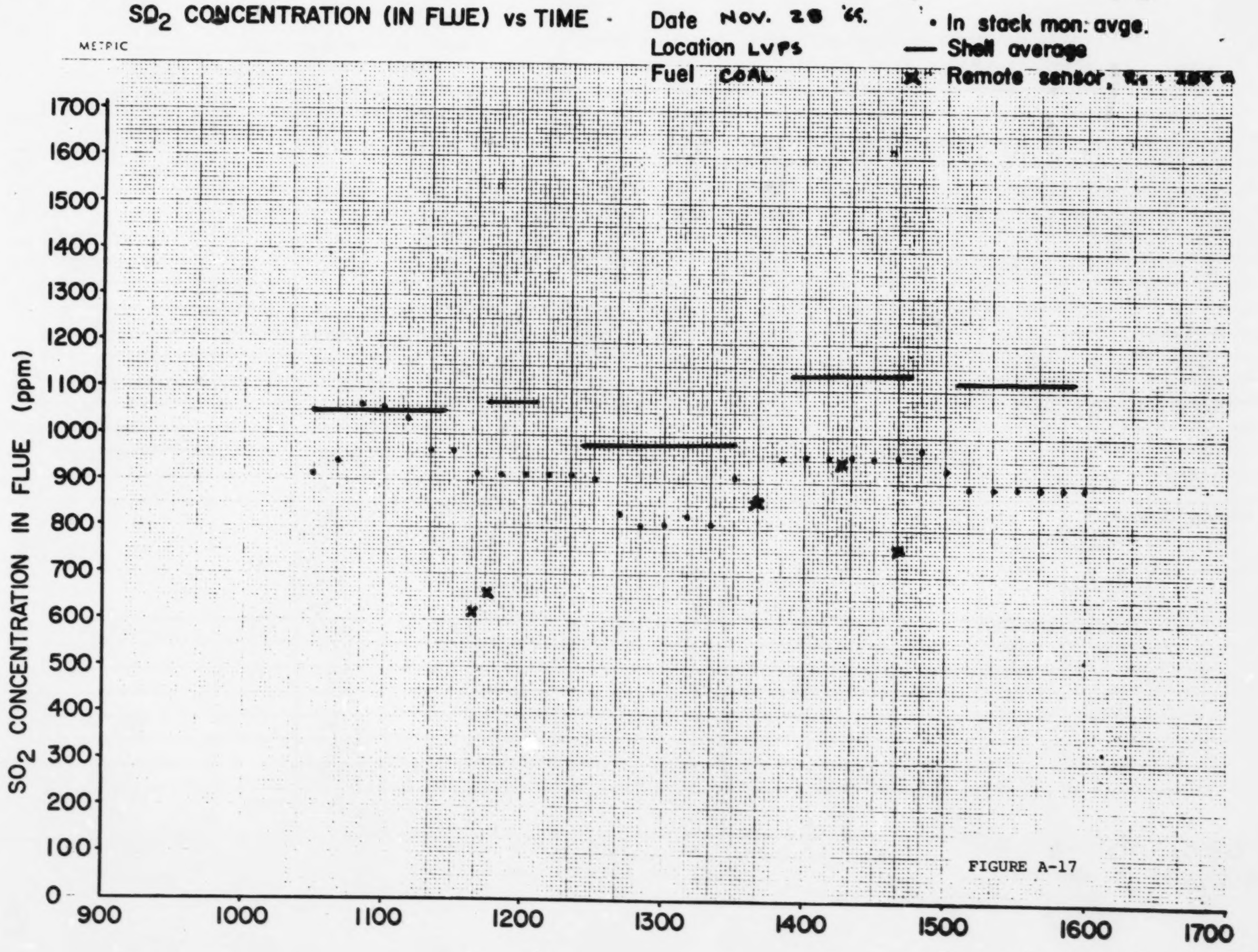


FIGURE A-16



SO$_2$ CONCENTRATION (IN FLUE) vs TIME

Date Nov. 28 '66.
Location LVPS
Fuel COAL

FIGURE A-17

TABLE A-1

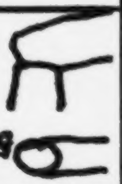
SO$_2$ REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = 2300 C_2L_2 = 1350

STACK LOCATION. LEVERS.

DATE. 2nd. OCT 1969.

Sensor Ser. No.

	No.	Note	1										
STACK	Ht (m)		42·7										
	Dia (m)		2·6										
	Temp. (°C)		14·9										
METEOR	Sky	(1)	10										
	Vis.	(2)	4		1	4					3	4	
	Wind (mph/°)	(3)	7/100	9/100		8/090					10/110	10/110	
	PLUME	(4)	WIND VERY LIGHT	→ SKY DARKENING		→	→		→ VERY LIGHT RAIN	→ LIGHT RAIN	→	STEADY RAIN	→
SITE	No.		P5	P5	P4	P4	P4	D1	D1	P3	P5	P5	P5
	& degree	(5)	19·5		14·16			3·67		9·33			
SENSOR	Time	(6)	9:30	9:45	1050	1100	1104	1114	1130	1150	1204	1300	1330
	Aperture		·5	·5	·5	·5	·5	·5	·5	·5	·5	·5	·5
	V_1 Div.	(7)	57	57	48	48	48	50·5	50·5	51·5	43	56	56
	V_2 Div.		31·5	31·5	27	27	27	26·5	26·5	27	24	30	30
	V_T Div.		36	36	25	25	22	6	10	19·5	20	27	27
RESULTS	AGC (volts)		5·6	5·8	5·6	6·0		6·3		6·4	6·5		5·2
	FOV. (m)		·21	·21	·29	·29	·29	1·11	1·11	·44	·21	·21	·21
	XLT. (m)		2·76	2·76	2·68	2·68	2·68	2·61	2·61	2·63	2·76	2·76	2·76
	R_s (m)		128	128	175	175	175	667	667	263	128	128	128
	Temp. Factor		1·4	1·4	1·4	1·4	1·4	1·4	1·4	1·4	1·4	1·4	1·4
	SENSOR (ppm) AT STACK EXIT		809	809	645	645	554	151	255	503	554	610	610
	SENSOR (ppm) AT FLUE												
	SHELL (ppm)												

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation an plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. .....

TABLE A-1 (cont)

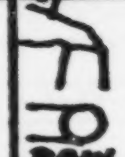
SO$_2$ REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = 2900 C_2L_2 = 1350

STACK LOCATION LEVERS

DATE 2nd OCT 1969

Sensor Ser. No.

		Note												
	No.		1											
STACK	Ht (m)		42·7											
	Dia (m)		2·6											
	Temp. (°C)		149											
METEOR	Sky	(1)	10											
	Vis.	(2)	4	2		3		2·5						
	Wind (mph/°)	(3)	9/090			12/080		13/080						
	PLUME	(4)	 RAIN STOPPED											
SITE	No.		P5	25	P5	P5	P5	P5	P5	P5				
	∠ degree	(5)												
SENSOR	Time	(6)	1350	1410	1420	1452	1500	1508	1600	1608				
	Aperture		·5											
	V_1 Div.	(7)	56	56		48			47					
	V_2 Div.		30	30		25			29					
	V_T Div.		27	28	27	24	24	21	21	20				
RESULTS	AGC (volts)			5·6				5·2						
	FOV. (m)		·21											
	XLT. (m)		2·78											
	R_s (m)		128											
	Temp. Factor		1·4											
	SENSOR (ppm) AT STACK EXIT		610	636	610	658	658	568	450	423				
	SENSOR (ppm) AT FLUE													
	SHELL (ppm)													

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ......

TABLE A-2

SO_2 REMOTE SENSOR DATA SHEET

Sensor Ser. No. DEMO

REF. CELL C_1L_1 = 2900 C_2L_2 = 1350

STACK LOCATION. LEVERS

DATE. 3RD. OCT. 1969.

	No.	Note	1										
STACK	Ht (m)		42·7										
	Dia (m)		2·6										
	Temp. (°C)		149										
METEOR	Sky	(1)	9							10			
	Vis.	(2)	6	6						7			
	Wind (mph/°)	(3)	15-25	16/320						12/330			
	PLUME	(4)											
SITE	No.		P6										
	& degree	(5)	22										
SENSOR	Time	(6)	1055	1110	1112	1115	1118	1123	1140	1150	1200	1210	1218
	Aperture		·5										
	V_1 Div.	(7)	51									54	54
	V_2 Div.		28									30	30
	V_T Div.		27	27	18	28	19	24·5	24	30	23	23	27
RESULTS	AGC (volts)		5·1		5·2-5·4								
	FOV. (m)		0·19										
	XLT. (m)		2·8										
	R_s (m)		114										
	Temp. Factor		1·41										
	SENSOR (ppm) AT STACK EXIT		649	649	408	677	434	579	566	735	539	496	597
	SENSOR (ppm) AT FLUE												
	SHELL (ppm)												

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-2 (cont.)

SO$_2$ REMOTE SENSOR DATA SHEET

STACK LOCATION. LEVERS.

Sensor Ser. No.

REF. CELL C_1L_1 = 2900 C_2L_2 = 1300

DATE. 3RD. OCT. 1969

	No.	Note	1											
STACK	Ht (m)		42·7											
	Dia (m)		2·6											
	Temp. (°C)		149											
METEOR	Sky	(1)			9				7				2	
	Vis.	(2)			8				10				12	
	Wind (mph/°)	(3)			10/330				14/310				12/320	
	PLUME	(4)	HEAVY OVERCAST PLUME INVISIBLE											
SITE	No.		P6											
	& degree	(5)	22											
SENSOR	Time	(6)	1240	1250	1300	1325	1340	1350	1410	1420	1430	1450	1500	
	Aperture													
	V_1 Div.	(7)	54			54			53					
	V_2 Div.		30			30			29					
	V_T Div.		29	25	28	33	26	23	25	29	21	26	21·5	
RESULTS	AGC (volts)													
	FOV. (m)		0·19											
	XLT. (m)		2·8											
	R_s (m)		114											
	Temp. Factor		1·41											
	SENSOR (ppm) AT STACK EXIT		650	546	624	760	571	496	570	677	467	596	470	
	SENSOR (ppm) AT FLUE													
	SHELL (ppm)													

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-2 (cont.)

SO_2 REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = 2900 C_2L_2 = 1350

STACK LOCATION. LEVERS

DATE. 3RD. OCT. 1969

Sensor Ser. No.

		Note											
STACK	No.		1										
	Ht (m)		42·7										
	Dia (m)		2·6										
	Temp. (°C)		149										
METEOR	Sky	(1)				1							
	Vis.	(2)				15+							
	Wind (mph/°)	(3)				14/320							
	PLUME	(4)											
SITE	No.		P6	B1	B1	C3	C3						
	& degree	(5)	22	5·5	5·5	11·67	11·67						
SENSOR	Time	(6)	1505	1525	1535	1605	1610						
	Aperture		·5		·25								
	V_1 Div.	(7)	53	47	42	43	43						
	V_2 Div.		29	25	22	22	22						
	V_T Div.		26	15	17	22	18						
RESULTS	AGC (volts)												
	FOV. (m)		0·19	0·74	0·74	0·18	0·18						
	XLT. (m)		2·8	2·61	2·61	2·65	2·65						
	R_s (m)		114	446	446	211	211						
	Temp. Factor		1·41	1·41	1·41	1·41	1·41						
	SENSOR (ppm) AT STACK EXIT		570	413	547	715	575						
	SENSOR (ppm) AT FLUE												
	SHELL (ppm)												

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-3

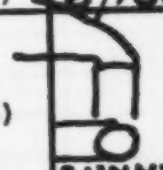
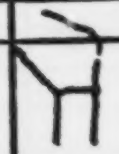
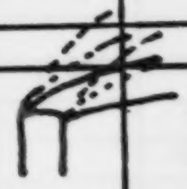
STACK LOCATION. LEVERS

DATE. 6TH OCT 1969

SO_2 REMOTE SENSOR DATA SHEET

REF. CELL $C_1L_1 = 2900$ $C_2L_2 = 1350$

Sensor Ser. No.

	No.	Note	1										
STACK	Ht (m)		42·7										
	Dia (m)		2·6										
	Temp. (°C)		149										
METEOR	Sky	(1)	4										
	Vis.	(2)	6										
	Wind (mph/°)	(3)	6/160										
	PLUME	(4)	 SUNNY HAZY LIGHT CLOUD					 WIND DIRECTION CHANGED				 VARIABLE	
SITE	No.		P5									P6	
	& degree	(5)	19·5									22·0	
SENSOR	Time	(6)	1050	1052	1053	1054	1100	1101	1103	1104	1105	1130	1132
	Aperture		·5									·5	
	V_1 Div.	(7)	63									61·5	
	V_2 Div.		34									34	
	V_T Div.		38·5	35	28	40	38·5	25·5	39·5	24·5	38	35	33·5
RESULTS	AGC (volts)											·19	
	FOV. (m)		·23									2·80	
	XLT. (m)		2·76									114	
	R_s (m)		128										
	Temp. Factor		1·37										
	SENSOR (ppm) AT STACK EXIT		776	694	537	812	776	483	800	462	764	683	648
	SENSOR (ppm) AT FLUE		1070	956	740	1120	1070	666	1102	637	1052	942	893
	SHELL (ppm)				1021								

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-3 (CONT).

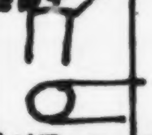
SO$_2$ REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = 2900 C_2L_2 = 1350

STACK LOCATION LEVERS.

DATE 6TH OCT 1969.

Sensor Ser. No.

	No.	Note	1										
STACK	Ht (m)												
	Dia (m)												
	Temp. (°C)												
METEOR	Sky	(1)							6				9
	Vis.	(2)							6				4
	Wind (mph/°)	(3)							6/140				16/80
	PLUME	(4)						PLUME NOT VISIBLE AGAINST CLOUD			10% FILTERS BRIGHT OVERCAST		
SITE	No.		P6										
	& degree	(5)	22.0										
SENSOR	Time	(6)	1134	1136	1138	1140	1145	1148	1200	1204	1206	1210	1340
	Aperture								0.5				
	V_1 Div.	(7)	61.5						62				62
	V_2 Div.		34						33				32
	V_T Div.		37.5	40	35.5	42	35	36	35	35.5	28.5	36	40
RESULTS	AGC (volts)												
	FOV. (m)		.19										
	XLT. (m)		2.80										
	R_s (m)		114										
	Temp. Factor		1.37										
	SENSOR (ppm) AT STACK EXIT		742	804	695	854	683	707	706	717	559	729	847
	SENSOR (ppm) AT FLUE		1022	1110	890	1168	942	975	975	990	771	1005	1165
	SHELL (ppm)					924							

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-3 (CONT)

STACK LOCATION. LEVERS

DATE. 6TH OCT 1969

SO$_2$ REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = 2800 C_2L_2 = 1350

Sensor Ser. No.

	No.	Note	1										
STACK	Ht (m)												
	Dia (m)												
	Temp. (°C)												
METEOR	Sky	(1)							9				8
	Vis.	(2)							4				4
	Wind (mph/°)	(3)							6/80				8/100
	PLUME	(4)								GS	PLUME FROM HEARNE INUNDATING AREA (STRONG SMELL)		
SITE	No.		P6										
	& degree	(5)	22.0										
SENSOR	Time	(6)	1345	1350	1351	1353	1355	1357	1403	1420	1427	1433	1449
	Aperture		.5										
	V_1 Div.	(7)	62							58			55
	V_2 Div.		32							30			30
	V_T Div.		40	32	40.5	39	35.5	38.5	35.5	33	23.5	29	36
RESULTS	AGC (volts)												
	FOV. (m)		·19										
	XLT. (m)		2.80										
	R_s (m)		114										
	Temp. Factor		1·37										
	SENSOR (ppm) AT STACK EXIT		847	660	859	823	740	811	740	753	505	635	820
	SENSOR (ppm) AT FLUE		1170	910	1185	1136	1021	1120	1020	1040	696	876	1130
	SHELL (ppm)					1008							

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-3 (CONT)

SO$_2$ REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = 2900 C_2L_2 = 1350

STACK LOCATION LEVERS

DATE 6TH OCT 1969

Sensor Ser. No.

	No.	Note	1										
STACK	Ht (m)												
	Dia (m)												
	Temp. (°C)												
METEOR	Sky	(1)	8								9		
	Vis.	(2)	4						2-3		4		
	Wind (mph/°)	(3)	8/100								10/90		
	PLUME	(4)	VERY HAZY			BRIGHT OVERCAST			VERY HAZY				
SITE	No.		P6			C3		C4					
	∠ degree	(5)	22·0			11·67		8·0					
SENSOR	Time	(6)	1514	1516	1518	1532	1536	1646	1649	1557	1600		
	Aperture		·5	·25		·25		·25					
	V_1 Div.	(7)	54			53		50					
	V_2 Div.		31			27		26·5					
	V_T Div.		14	11	15	19	20	16	23	19	21		
RESULTS	AGC (volts)												
	FOV. (m)		0·19			0·18		0·25					
	XLT. (m)		2·80			2·65		2·63					
	R_s (m)		114			211		307					
	Temp. Factor		1·37			1·37		1·37					
	SENSOR (ppm) AT STACK EXIT		261	201	282	478	504	403	601	486	543		
	SENSOR (ppm) AT FLUE		360	277	389								
	SHELL (ppm)		915										

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

SO$_2$ REMOTE SENSOR DATA SHEET

Sensor Ser. No. DEMO

REF. CELL C_1L_1 =2900 C_2L_2 =1350

STACK LOCATION. LEVER BROS.

DATE 7/10/69

	No.	Note	1										
STACK	Ht (m)		42.7	"	"	"	"	"	"	"	"	"	"
	Dia (m)		2.6	"	"	"	"	"	"	"	"	"	"
	Temp. (°C)		150	"	"	"	"	"	"	"	"	"	"
METEOR	Sky	(1)	10										
	Vis.	(2)											
	Wind (mph/°)	(3)											
	PLUME	(4)								light rain			
SITE	No.		P6	"	"	"	"	"	"	"	"	"	"
	& degree	(5)	23.0	"	"	"	"	"	"	"	"	"	"
SENSOR	Time	(6)	0954	0959	1004	1010	1016	1020	1023	1040	1045	1050	1055
	Aperture		.5	"	"	"	"	"	"	.25	"	"	"
	V_1 Div.	(7)	59	"	"	"	57.	"	"	57.5	"	"	"
	V_2 Div.		31	"	"	"	31.	"	"	30.5	"	"	"
	V_T Div.		30.5	30.	31.	29.	29	29.5	30	27.5	27	29	28
RESULTS	AGC (volts)									5.4			
	FOV. (m)		.18	"	"	"	"	"	"	.09	"	"	"
	XLT. (m)		2.82	"	"	"	"	"	"	"	"	"	"
	R_s (m)		110	"	"	"	"	"	"	"	"	"	"
	Temp. Factor		1.44	"	"	"	"	"	"	"	"	"	"
	SENSOR (ppm) AT STACK EXIT		675	662	688	638	636	649	662	612	599	649	624
	SENSOR (ppm) AT FLUE		931	914	949	881	877	895	914	845	826	895	861
	SHELL (ppm)					←		950		→			

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-4 (cont)

STACK LOCATION LEVER BROS.

DATE 7/10/69

SO$_2$ REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = 2900 C_2L_2 = 1350

Sensor Ser. No. DEMO

		Note											
STACK	No.		1	"	"	"	"	"	"	"	"	"	"
	Ht (m)		42.7	"	"	"	"	"	"	"	"	"	"
	Dia (m)		2.6	"	"	"	"	"	"	"	"	"	"
	Temp. (°C)		150	"	"	"	"	"	"	"	"	"	"
METEOR	Sky	(1)											
	Vis.	(2)	2-3 mi										
	Wind (mph/°)	(3)											
	PLUME	(4)			Blowing Tubes							Thick Black Smoke	
SITE	No.		~C3	C5	"	"	"	"	"	C4	"	"	"
	& degree	(5)	12.5	10.5	"	"	"	"	"	8.0	"	"	"
SENSOR	Time	(6)	1116	1125	1126	1127	1128	1129	1130	1140	1141^{-}	1141	1141^{+}
	Aperture		.5	"	"	"	"	"	"	"	.25	"	"
	V_1 Div.	(7)	58	"	"	"	"	"	"	56	"	"	"
	V_2 Div.		31	"	"	"	"	"	"	30	"	"	"
	V_T Div.		23	23	13	18	16	19.5	22.	14	5	0	5
RESULTS	AGC (volts)									6.1			
	FOV. (m)		.33	.39	"	"	"	"	"	.51	.25	"	"
	XLT. (m)		2.66	2.64	"	"	"	"	"	2.63	"	"	"
	R_s (m)		197	234	"	"	"	"	"	307	"	"	"
	Temp. Factor		1.44	"	"	"	"	"	"	"	"	"	"
	SENSOR (ppm) AT STACK EXIT		521	525	284	402	354	438	500	319	110	0	110
	SENSOR (ppm) AT FLUE		719	724	392	556	488	605	690	440	152	0	152
	SHELL (ppm)		←960→										

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-4 (cont.)

SO_2 REMOTE SENSOR DATA SHEET

Sensor Ser. No. DEMO

REF. CELL C_1L_1 = 2900 C_2L_2 = 1350

STACK LOCATION LEVER BROS.

DATE 7/10/'69

		Note											
STACK	No.		1										
	Ht (m)		42.7	"	"	"	"	"	"	"	"	"	"
	Dia (m)		2.6	"	"	"	"	"	"	"	"	"	"
	Temp. (°C)		150	"	"	"	"	"	"	"	"	"	"
METEOR	Sky	(1)											
	Vis.	(2)								2 mi			
	Wind (mph/°)	(3)							0				
	PLUME	(4)			← Heavy rain →	Very Heavy		Sky Clearing & Wind Dropping					
SITE	No.		B1	P6	P6	P6		S1	S2	S3	S4		
	& degree	(5)	5.67	23.0	"	"		5.8	5.0	4.7	3.7		
SENSOR	Time	(6)	1156	1211	1215	1217		1410	1428	1448	1500		
	Aperture		.25	.5	"	"		.5	.25	"	"		
	V_1 Div.	(7)	55	60	"	"		58	58	55	53		
	V_2 Div.		30	30	"	"		32	31	30	28.5		
	V_T Div.		26	23	25	23		21	17.5	13	11		
RESULTS	AGC (volts)												
	FOV. (m)		.36	.18	"	"		.7	.41	.43	.55		
	XLT. (m)		2.61	2.82	"	"		2.61	2.61	2.61	2.61		
	R_s (m)		432	110	"	"		423	489	521	662		
	Temp. Factor		1.44	"	"	"		"	"	"	"		
	SENSOR (ppm) AT STACK EXIT		630	519	567	519		458	395	293	263		
	SENSOR (ppm) AT FLUE		868	717	783	717		632	545	390	363		
	SHELL (ppm)		← 900 →										

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-4 (Cont.)

STACK LOCATION. LEVER BROS

DATE... 7/10/'69........

SO_2 REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = 2900 C_2L_2 = 1350

Sensor Ser. No. DEMO

	No.	Note	1											
STACK	Ht (m)		42.7											
	Dia (m)		2.6											
	Temp. (°C)		150											
METEOR	Sky	(1)												
	Vis.	(2)												
	Wind (mph/°)	(3)												
	PLUME	(4)	light rain	Clearing										
SITE	No.		P3	P5	P5	P5								
	& degree	(5)	9.3	19.3	"	"								
SENSOR	Time	(6)	1527	1605	1610	1618								
	Aperture		.25	.5	"	"								
	V_1 Div.	(7)	55	50	"	"								
	V_2 Div.		30	31	"	"								
	V_T Div.		24	31	24.5	36								
RESULTS	AGC (volts)				5.9	5.6								
	FOV. (m)		.22	.21	.10	.10								
	XLT. (m)		2.63	2.75	"	"								
	R_s (m)		264	129	"	"								
	Temp. Factor		1.44	"	"	"								
	SENSOR (ppm) AT STACK EXIT		570	705	513	876								
	SENSOR (ppm) AT FLUE		786	973	708	1210								
	SHELL (ppm)		←980→											

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

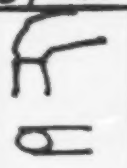
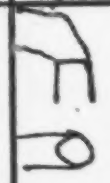
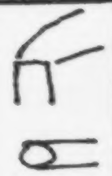
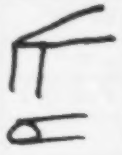
TABLE A-5

STACK LOCATION LEVER BRØS.
DATE ØCT. 9th '69

SO$_2$ REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = 2900 C_2L_2 = 1350

Sensor Ser. No.

		Note												
	No.		1											
STACK	Ht (m)		42.7											
	Dia (m)		2.6											
	Temp. (°C)		150											
METEOR	Sky	(1)			10			20					10	
	Vis.	(2)	12 EST.		15			15					12	
	Wind (mph/°)	(3)	6/260		8/		8/150	8/					12/	
	PLUME	(4)												
SITE	No.		C3	C3	C5	C4	P5	P6N	"	"	"	C4		
	& degree	(5)	9.67	9.67	7.67	6.5	19.8	19.8	"	"	"	6.5		
SENSOR	Time	(6)	1140	1143	1210	1221	1225	1330	1335	1337	1340	1550	1556	1605
	Aperture		.5	.25	.25	.25	.25	.5	.5	.5	.5	.5	"	.25
	V$_1$ Div.	(7)	66	"	66	65	66	66	66	66	66	42	"	36.5
	V$_2$ Div.		35	"	35.5	36	36	35	35	35	35	24	"	19.5
	V$_T$ Div.		28	30	34	27.5	49	34.5	33	33	31	20	18.	19.
RESULTS	AGC (volts)													
	FOV. (m)		.42	.21	.27	.31	.10	.21	"	"	"	.63	.63	.31
	XLT. (m)		2.64	"	2.62	2.62	2.76	2.76	"	"	"	2.62	"	"
	R$_s$ (m)		254	"	320	377	126	126	"	"	"	377	"	"
	Temp. Factor		1.44	1.44	"	"	"	"	"	"	"	"	"	"
	SENSOR (ppm) AT STACK EXIT		573	619	704	542	1022	691	658	658	613	594	524	721
	SENSOR (ppm) AT FLUE		790	855	971	748	1410	952	907	907	845	820	723	995
	SHELL (ppm)													

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-5 (Cont.)

SO$_2$ REMOTE SENSOR DATA SHEET

STACK LOCATION LEVERS

Sensor Ser. No.

REF. CELL C_1L_1 = 2900 C_2L_2 =

DATE 9TH OCT. 1969.

	No.	Note											
STACK	Ht (m)												
	Dia (m)												
	Temp. (°C)												
METEOR	Sky	(1)				10					10		
	Vis.	(2)				15					15		
	Wind (mph/°)	(3)				6/					11/		
	PLUME	(4)						SUNNY HIGH CLOUD					
SITE	No.		P6N								P6-C3	C3	C5
	& degree	(5)	19.8								12.5	9.67	7.67
SENSOR	Time	(6)	1348	1350	1353	1355	1400	1405	1412	1428	1510	1520	1533
	Aperture		.5	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5
	V_1 Div.	(7)	51.5								52	49	45
	V_2 Div.		29								27.5	26	24
	V_T Div.		32	37	46	41	40	35	29	26.5	33	25	21
RESULTS	AGC (volts)												
	FOV. (m)		.21										
	XLT. (m)		2.76								.33	.42	.53
	R_s (m)		126								2.66	2.64	2.62
	Temp. Factor		1.44								197	254	320
	SENSOR (ppm) AT STACK EXIT		794	956	1283	1095	1059	889	703	630	899	704	636
	SENSOR (ppm) AT FLUE		1095	1318	1770	1510	1460	1227	969	868	1240	970	877
	SHELL (ppm)												

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-5 (cont.)

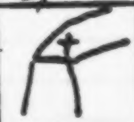
SO$_2$ REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = C_2L_2 =

STACK LOCATION. LEVERS....

DATE. OCT. 9............

Sensor Ser. No.

No.	Note											
Ht (m)												
Dia (m)												
Temp. (°C)												
												10
Sky	(1)											15
Vis.	(2)											6/
Wind (mph/°)	(3)											
PLUME	(4)	—	15	16		SO$_2$ INJECTED						
No.		PGN										
& degree	(5)	19.8										
Time	1350	1351	1352	1353	1354	1354.5	1355	1356	1357	1358	1359	1400
Aperture		.5	—	—	—	—	—	—	—			
V_1 Div.	(7)	31.5										
V_2 Div.		29										
V_T Div.	32.5	~~32.5~~ 31.5	37	35	35	46	43	41	39	40	39	41
AGC (volts)												
FOV. (m)												
XLT. (m)												
R_s (m)												
Temp. Factor												
SENSOR (ppm) AT STACK EXIT	810	778	956	889	922	1283	1168	1095	1024	1059	1024	1094
SENSOR (ppm) AT FLUE	1117	1074	1319	1227	1273	1770	1612	1511	1413	1462	1413	1511
SHELL (ppm)												

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-5 (cont.)

SO_2 REMOTE SENSOR DATA SHEET

Sensor Ser. No.

REF. CELL C_1L_1 = C_2L_2 =

STACK LOCATION............

DATE....................

	No.	Note											
STACK	Ht (m)												
	Dia (m)												
	Temp. (°C)												
METEOR	Sky	(1)											
	Vis.	(2)											
	Wind (mph/°)	(3)											
	PLUME	(4)	1516. SO_2 INJECTED.										
SITE	No.												
	& degree	(5)											
SENSOR	Time	(6)	1401	1402	1403	1404	1405	1406	1407	1408	1409	1409.35	1410
	Aperture		.5										
	V_1 Div.	(7)	51.5										
	V_2 Div.		29										
	V_T Div.		39.5	37.5	40	36	35	31.5	30	27	28	34	27
RESULTS	AGC (volts)												
	FOV. (m)												
	XLT. (m)												
	R_s (m)												
	Temp. Factor												
	SENSOR (ppm) AT STACK EXIT	1	1042	973	1059	922	889	778	733	649	673	857	649
	SENSOR (ppm) AT FLUE		1437	1342	1462	1273	1227	1074	1011	889	929	1183	889
	SHELL (ppm)												

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-6

SO$_2$ REMOTE SENSOR DATA SHEET

Sensor Ser. No. DEMO.

REF. CELL C_1L_1 = 6315 C_2L_2 = 3935

STACK LOCATION..LVPS....
DATE..24/11/69.....

	No.	Note	4	"	"	"	"	"	"	"	"	"	"
STACK	Ht (m)		150	"	"	"	"	"	"	"	"	"	"
	Dia (m)		5.4	"	"	"	"	"	"	"	"	"	
	Temp. (°C)		124	"	"	"	"	"	"	"	"	"	
METEOR	Sky	(1)	0	"	"	"	"	"	"	"	"	"	
	Vis.	(2)	15+	"	"	"	"	"	"	"	"	"	
	Wind (mph/°)	(3)	0-5/315	"	"	"	"	"	"	"	"	"	
	PLUME	(4)											
SITE	No.		56	58	59	510	511	511	56	56	56	58	
	& degree	(5)	34	24.3	18.8	15.8	13.5	13.5	34	34	34	24.3	
SENSOR	Time	(6)	1050	1100	1110	1120	1130	1140	1200	1215	1220	1230	
	Aperture		·5	"	"	"	"	"	"	"	"	"	
	V_1 Div.	(7)	62	60	59	57	55	75	76	77	77	69	
	V_2 Div.		44	43	42	40	39	53	51	55	55	47	
	V_T Div.		54	45	40	37	31	43	63	57	49	38	
RESULTS	AGC (volts)												
	FOV. (m)		·45	·61	·77	·91	1·07	1·07	·45	·45	·45	·61	
	XLT. (m)		6·51	5·92	5·70	5·61	5·55	5·55	6·51	6·51	6·51	5·92	
	R_s (m)		265	365	465	550	650	650	265	265	265	365	
	Temp. Factor		1·35	"	"	"	"	"	"	"	"	"	
	SENSOR (ppm) AT STACK EXIT		1073	934	874	858	717	736	1043	855	702	687	
	SENSOR (ppm) AT FLUE												
	SHELL (ppm)		←	1315	→		.	←	1360	→			

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-6 (Cont.)

SO$_2$ REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = 6315 C_2L_2 = 3935

STACK LOCATION. LYPS.....

Sensor Ser. No. DEMO

DATE....24/11/69........

STACK	No.	Note	4	..	..	..	..	..	..	..			
	Ht (m)		150	..	..	..	..	..	..	..			
	Dia (m)		5·4	..	..	..	..	..	..	..			
	Temp. (°C)		124	..	..	..	..	..	..	..			
METEOR	Sky	(1)	0	..	..	..	..	..	..	..			
	Vis.	(2)	15+	..	..	..	..	..	..	..			
	Wind (mph/°)	(3)	6/180	..	..	..	..	..	..	..			
	PLUME	(4)	SHUT DOWN						SUN INTER-FERING				
SITE	No.		56	56	..	..	..	..	..	..	..		
	& degree	(5)	34·	..	..	..	..	..	..	..	..		
SENSOR	Time	(6)	1324	1325	1419	1418	1422	1424	1525	1530			
	Aperture		·5	..	..	..	..	..	..	..			
	V_1 Div.	(7)	69	69	67	..	..	..	65	..			
	V_2 Div.		47	47	48	..	..	..	46	..			
	V_T Div.		3	0	13	15	15	15	62	66			
RESULTS	AGC (volts)												
	FOV. (m)		·45	..	..	..	..	..	..	..			
	XLT. (m)		6·51	..	..	..	..	..	..	..			
	R_s (m)		265	..	..	..	..	..	..	..			
	Temp. Factor		1·38	..	..	..	..	..	..	..			
	SENSOR (ppm) AT STACK EXIT		43·6	0	175	204	204	204	1197	1312			
	SENSOR (ppm) AT FLUE												
	SHELL (ppm)	FROM 1325	— 540						←1470 ——→ TO 1550				

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-6 (Cont.)

SO$_2$ REMOTE SENSOR DATA SHEET

STACK LOCATION LVPS

Sensor Ser. No. DEMO

REF. CELL C_1L_1 = 6315 C_2L_2 = 3935

DATE 24/11/69

	No.	Note	4	"	"	"	"	"	"				
STACK	Ht (m)		150	"	"	"	"	"	"				
	Dia (m)		5.4	"	"	"	"	"	"				
	Temp. (°C)		124	"	"	"	"	"	"				
METEOR	Sky	(1)	0	"	"	"	"	"	"				
	Vis.	(2)	15	"	"	"	"	"					
	Wind (mph/°)	(3)	5-10/180	"	"	"	"	"					
	PLUME	(4)		CLOSE TO SUN					CLOUDING OVER				
SITE	No.		S8	S9	S10	S11	S6	S8	S9				
	& degree	(5)	24.3	18.8	15.8	13.5	34.	24.3	18.8				
SENSOR	Time	(6)	1540	1548	1555	1600	1615	1620	1630				
	Aperture		.5	"	"	"	1.0	"	"				
	V_1 Div.	(7)	66	64	58	60	87	86	80				
	V_2 Div.		47	46	40	42	60	60	65				
	V_T Div.		61	56	45	45	86	82	70				
RESULTS	AGC (volts)				6.6	6.2-6.9	5.8-6.9	6.0-6.7	7.0				
	FOV. (m)		.61	.77	.9	1.07	.89	1.21	1.5				
	XLT. (m)		5.92	5.7	5.61	5.55	6.51	5.92	5.7				
	R_s (m)		365	465	550	645	265	365	465				
	Temp. Factor		1.35	"	"	"	"	"	"				
	SENSOR (ppm) AT STACK EXIT		1256	1200	1073	1023	1263	1321	1066				
	SENSOR (ppm) AT FLUE												
	SHELL (ppm)	←	FROM 15:20 1470 →										

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-7

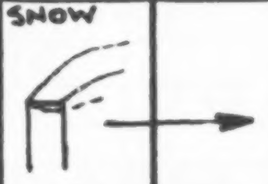
SO$_2$ REMOTE SENSOR DATA SHEET

STACK LOCATION. LVPS.....

Sensor Ser. No. DEMO

REF. CELL C_1L_1 = 3935 C_2L_2 = 2838

DATE...27/11/69.......

	No.	Note	4	..	..	..	..	..	..	..	..	..	..
STACK	Ht (m)		150	..	..	..	..	..	..	..	..	..	..
	Dia (m)		5.4	..	..	..	..	..	..	..	..	..	..
	Temp. (°C)		94	..	..	..	..	..	..	..	..	..	..
METEOR	Sky	(1)	10	..	..	..	..	..	..	..	..	..	..
	Vis.	(2)	4mi	..	..	..	..	..	..	..	..	..	..
	Wind (mph/°)	(3)	5/65 SNOW	..	..	..	..	..	..	..	..	..	..
	PLUME	(4)											
SITE	No.		NW1	NW2	NW2	NW2	NW3	NW4	NW1	NW2	NW3	NW4	NW5
	& degree	(5)	24.	20	20	20	15	11.8	24.	20	15	11.8	9.8
SENSOR	Time	(6)	1342	1350	1400	1410	1420	1430	1440	1445	1450	1500	1510
	Aperture		.5	..	..	..	..	..	1.0	..	..	..	..
	V_1 Div.	(7)	79	77	78	75	73	74	71	74	70	67	68
	V_2 Div.		59	60	60	58	57	58	54	57	52	51	53
	V_T Div.		62	57	60	52	40	51	59	58	48	39	35
RESULTS	AGC (volts)		5.6-5.8	5.6		6.2	6.4	6.4	5.7	5.9	6.1	6.3	6.5
	FOV. (m)												
	XLT. (m)												
	R_s (m)		370	440	440	440	580	730	370	440	580	730	880
	Temp. Factor												
	SENSOR (ppm) AT STACK EXIT		620	567	604	529	403	535	652	617	570	463	384
	SENSOR (ppm) AT FLUE												
	SHELL (ppm)				←				1040				→

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ......

TABLE A-8

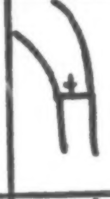
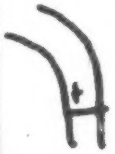
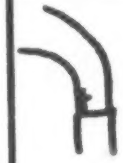
SO$_2$ REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 = 3933 C_2L_2 = 2838

STACK LOCATION. LVPS.....

DATE. NOV. 28 '69.....

Sensor Ser. No. DEMO.

		Note											
	No.		4	"	"	"	"	"	"	"	"	"	"
STACK	Ht (m)		150	150	147	144	144	150	150	150	150	150	144
	Dia (m)		5.4	"	"	"	"	"	"	"	"	"	"
	Temp. (°C)		98	"	"	"	"	"	"	"	"	"	"
METEOR	Sky	(1)	10	10	10	9	9	9	8	7	6	5	1
	Vis.	(2)	12 mi										
	Wind (mph/°)	(3)	8/300						Veering	to 270°			
	PLUME	(4)							Plume Same Shape.				
SITE	No.		S6	S8	S9	S10	S11	S6	S6	S8	S8	S8	S9
	& degree	(5)	34.	24.3	18.8	15.8	13.5	34.	34	24.3	24.3	24.3	18.8
SENSOR	Time	(6)	1018	1028	1038	1045	1055	1105	1108	1115	1117	1120	1129
	Aperture		.5	"	"	"	"	"	"	"	"	"	"
	V_1 Div.	(7)	2.63	2.60	2.6	2.56	2.54	2.5	2.5	2.5	2.5	2.5	2.4
	V_2 Div.		3.46	3.38	3.35	3.33	3.22	3.25	3.25	3.25	3.25	3.25	3.2
	V_T Div.		3.28	3.35	2.85	2.70	2.33	2.87	3.05	2.58	2.73	2.5	2.64
RESULTS	AGC (volts)		5.5	5.6	5.5	5.6	5.4	5.2	5.25	5.2	5.2	5.2	5.1
	FOV. (m)		.45	.61	.76	.88	1.02	.95	.95	.61	.61	.61	.76
	XLT. (m)		6.51	5.92	5.70	5.61	5.55	6.51	6.51	5.92	5.92	5.92	5.70
	R_s (m)		265	365	465	550	640	265	265	365	365	365	465
	Temp. Factor		1.29	"	"	"	"	"	"	"	"	"	"
	SENSOR (ppm) AT STACK EXIT		692	812	691	667	565	638	689	607	659	592	685
	SENSOR (ppm) AT FLUE												
	SHELL (ppm)				◄——	——	1050	——	——	——	——	——►	

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-8 (cont.)

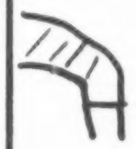
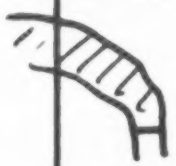
SO$_2$ REMOTE SENSOR DATA SHEET

Sensor Ser. No. DEMO

REF. CELL C_1L_1 =3933 C_2L_2 =2838

STACK LOCATION. LVPS.....

DATE. NOV 28 '69.......

	No.	Note	4	"	"	"	"	"	"				
STACK	Ht (m)		150	150	141	141	138	138	138				
	Dia (m)		5.4	"	"	"	"	"	"				
	Temp. (°C)		98										
			2										
METEOR	Sky	(1)	0		0	0	Widely scattered clouds						
	Vis.	(2)											
	Wind (mph/°)	(3)		15-20 /	~230°		~300°						
	PLUME	(4)											
SITE	No.		N7	N7	N3	N2	N4	N10	N10				
	& degree	(5)	31.0	31.0	25.3	21.0	17.0	12.3	12.3				
SENSOR	Time	(6)	1138	1145	1156	1207	1215	1228	1233				
	Aperture		.5	"	"	"	"	"	"				
	V_1 Div.	(7)	3.6	4.32	4.32	4.02	3.87	3.71	3.71				
	V_2 Div.		2.47	3.33	3.4	3.12	3.03	2.86	2.86				
	V_T Div.		2.8	3.8	4.47	4.06	4.13	3.54	3.28				
RESULTS	AGC (volts)		4.8	4.8	4.9	5.0	5.1	5.0	4.9				
	FOV. (m)		.48	.48	.55	.65	.78	1.09	1.09				
	XLT. (m)		6.30	6.30	5.97	5.78	5.65	5.65	5.65				
	R_s (m)		285	285	360	405	491	670	670				
	Temp. Factor		1.24	"	"	"	"	"	"				
	SENSOR (ppm) AT STACK EXIT		622	656	855	852	944	829	752				
	SENSOR (ppm) AT FLUE												
	SHELL (ppm)			←	1070	→		←	980 —				

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-8 (Cont.)

SO$_2$ REMOTE SENSOR DATA SHEET

Sensor Ser. No. DEMO

REF. CELL C_1L_1 = 3933 C_2L_2 = 2838

STACK LOCATION. LVPS

DATE. NOV. 28 '69

	No.	Note	4	"	"	"	"	"	"	"	"	"	"	
STACK	Ht (m)		138	150	141	138	138	150	150	150	141	138	138	
	Dia (m)		5.4	"	"	"	"	"	"	"	"	"	"	
	Temp. (°C)		98	"	"	"	"	"	"	"	"	"	"	
METEOR	Sky	(1)	1	1	1	2					1			
	Vis.	(2)	15+											
	Wind (mph/°)	(3)	15/250						15-20	GUSTY				
	PLUME	(4)	INVISIBLE								Estimate	Invisible		
SITE	No.		N10	N7	N1A	N11	N12	N7	N7	N7	N1A	N10	N11	
	& degree	(5)	12.17	31.	15.5	10.33	8.33	31.	31.	31.	15.5	12.17	10.33	
SENSOR	Time	(6)	1327	1338	1348	1358	1405	1416	1418	1420	1432	1442	1452	
	Aperture		0.5	"	"	"	"	"	"	"	"	"	"	
	V_1 Div.	(7)	3.63	3.85	3.62	3.5	3.48	3.65	3.65	3.65	3.38	3.36	3.28	
	V_2 Div.		2.78	2.95	2.87	2.75	2.66	2.82	2.82	2.82	2.6	2.63	2.54	
	V_T Div.		3.7	4.12	3.7	2.95	2.72	4.25	3.85	3.6	2.6	3.0	2.83	
RESULTS	AGC (volts)		5.2	5.1	5.2	5.3	5.5	5.2	5.2	5.2	5.6	5.5	5.7	
	FOV. (m)		1.09	.48	.88	1.28	1.58	.48	.48	.48	.88	1.09	1.28	
	XLT. (m)		5.52	6.30	5.60	5.49	5.96	6.30	6.30	6.30	5.60	5.52	5.49	
	R_s (m)		670	285	480	810	970	285	285	285	480	670	810	
	Temp. Factor		1.24	"	"	"	"	"	"	"	"	"	"	
	SENSOR (ppm) AT STACK EXIT		902	842	897	701	660	947	828	758	626	755	732	
	SENSOR (ppm) AT FLUE													
	SHELL (ppm)		—980→			←			1135			→		

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-8 (Cont.)

STACK LOCATION. LVPS.....

DATE. . NOV. 28. 69. . . . . .

SO$_2$ REMOTE SENSOR DATA SHEET

REF. CELL C_1L_1 =3933 C_2L_2 =2838

Sensor Ser. No. DEMO

	No.	Note	4										
STACK	Ht (m)		138	150	141	138	138	138					
	Dia (m)		5.4	"	"	"	"	"					
	Temp. (°C)		98	"	"	"	"	"					
METEOR	Sky	(1)	1										
	Vis.	(2)	15+										
	Wind (mph/°)	(3)	15-20/250										
	PLUME	(4)	Invisible										
SITE	No.		N12	N7	N1A	N10	N11	N12					
	∠ degree	(5)	8.33	31.	15.5	12.17	10.33	8.33					
SENSOR	Time	(6)	1502	1512	1523	1535	1545	1554					
	Aperture		0.5	"	"	"	"	"					
	V_1 Div.	(7)	3.27	3.5	3.35	3.2	3.15	2.96					
	V_2 Div.		2.52	2.65	2.68	2.5	2.45	2.35					
	V_T Div.		2.65	3.7	3.35	2.85	2.60	2.26					
RESULTS	AGC (volts)		5.8	5.4	5.9	6.2	6.5	6.7					
	FOV. (m)		1.58	.48	.88	1.09	1.28	1.58					
	XLT. (m)		5.46	6.30	5.60	5.52	5.49	5.46					
	R_s (m)		970	288	480	670	810	970					
	Temp. Factor		1.24	"	"	"	"	"					
	SENSOR (ppm) AT STACK EXIT		684	826	868	753	689	610					
	SENSOR (ppm) AT FLUE												
	SHELL (ppm)		←		1120			→					

Notes: (1) Cloud Cover in 10ths, Smoke (k), Haze (h), Fog (f), Etc; (2) (3) Note where taken; (4) Sketch elevation and plan (5) Hand-held Abney, (6) 2400 hr. clock local time; (7) volts from meter or divisions from chart. Opt. ....

TABLE A-9

	Range (meters)	Weather (Condition-Visibility in Miles)	Error Remote-Shell + 100%	Average Error %
V. Short Range	265	Clear 15	- 18.4	- 23.0
			- 23.3	
			- 37.1	
			- 19.2	
			- 18.5	
			- 10.7	
	285	Clear 15	- 16.6	
			- 27.0	
			- 33.2	
			- 26.2	
	265	Clear 12	- 38.7	- 25.8
		"	- 12.9	
		O'cast 12	- 39.2	- 36.8
		"	- 34.4	
Short Range	360	Clear 12	- 20.1	- 21.0
	365	Clear 15	- 29.0	
			+ 27.2*	
			- 14.5	
	405	Clear 12	- 20.4	
	365	O'cast 12	- 22.7	- 36.4
			- 42.2	
			- 37.2	
			- 43.6	
	370	O'cast 4	- 37.3	- 37.3
Medium Range	465	Clear 15	- 37.4	- 31.1
	"	"	- 18.4	
	480	"	- 44.8	
	"	"	- 22.5	
	550	"	- 27.0	
	550	Clear 12	- 36.5	
	465	O'cast 12	- 34.2	- 34.5
	465	"	- 34.8	
	440	O'cast 4	- 43.6	- 44.5
	440	"	- 49.1	
	"	"	- 40.7	
Long Range	650	Clear 15	- 31.2	- 23.4
	670	Clear 12	- 14.1	
			- 21.3	
			- 7.3	
			- 33.5	
			- 32.8	
	640	O'cast 12	- 46.2	- 46.2
	580	O'cast 4	- 61.2	- 53.2
	"	"	- 45.2	
V. Long Range	810	Clear 15	- 38.2	- 39.4
	"	"	- 38.5	
	970	"	- 41.8	
	"	"	- 39.0	

TABLE A-9 (Cont'd)

V. Long Range	Range	Weather	Error	Average Error
	730	O'cast 4	- 48.6	- 55.7
	"	"	- 55.5	
	880	"	- 63.1	

* Inconsistent

APPENDIX B

TABLE B.1

RUN IDENTIFICATION, FLIGHT 10

Run	Direction From/To	Altitude MSL	Altitude Ground	Direction	Ave ppm-m Value
1	E/W	5500	4500	Up	10
2	W/E	5500		Dn	60
3	E/W	5500		Dn	55
4	W/E	5500		Up	--
5	E/W	3500	2500	Up	20
6	W/E	3500		Dn	90
7	E/W	3500		Dn	70
8	W/E	2500	1500	Up	40
9	E/W	2500		Dn	140

TABLE B.2

RUN IDENTIFICATIONS FLIGHT 11

Run	Direction From/To	Altitude MSL	Altitude ft. above ground	Direction	Ave ppm-m Value
1	W/E	6000	5000	Up	-
2	E/W	6000	5000	Dn	15
3	W/E	6000	5000	Dn	25
4	E/W	6000	5000	Dn	25
5	W/E	5000	4000	Up	-
6	E/W	5100	4100	Dn	45
7	W/E	4000	3000	Up	45
8	E/W	3800	2800	Dn	75
9	W/E	3000	2000	Up	65
10	E/W	3000	2000	Dn	90
11	W/E	2000	1000	Up	75
12	E/W	2000	1000	Dn	110

TABLE B.3

FLIGHT 11 - AVERAGE VALUES

Col. 1 Height above ground	Col. 2 D'Ward	Col. 3 Upward ppm-m	Col. 4 2-3 gas below A/C
5000	25	0	25
4000	45	-	-
3000	75	45	30
2000	90	65	25
1000	110	75	35

TABLE B.4

FLIGHT 12 RUN IDENTIFICATION

Run	Direction	Altitude MSL	Altitude Ground	Direction	Ave ppm-m
1	W/E	6500	5500	Up	38
2	E/W	6500	5500	Dn	
3	W/E			Up	
4	E/W	6500	5500	Dn	42
5	W/E	6500	5500	Dn	55
6	E/W	6500	5500	Dn	51
7	W/E	3000	2000	Up	18
8	E/W	3000	2000	Dn	77
9	W/E	3000	2000	Dn	89
10	E/W	3000	2000	Up	29

TABLE B.5

RUN 12 - AVERAGE VALUES

Col. 1 Height above gd.	Col. 2 D'ward ppm-m	Col. 3 Up'wd ppm-m	Col. 4 2-3= gas below A/C	Col. 5 4/'m'	Col. 6 4/'m' ÷ 1 ppb
5,500	44	0	44	18	3.3
2,000	83	23	60	25	12.5

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